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INFLUENCE OF SEA SURFACE TEMPERATURE PRODUCTS FROM THE ATSR SERIES ON HADISST1 GLOBAL ANALYSES

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Executive summary

The Met Office Hadley Centre for Climate Prediction and Research (Hadley Centre) Sea Ice and Sea Surface Temperature (SST) data set, HadISST1, combines monthly globally complete fields of SST and sea ice concentration on a 1° latitude-longitude grid. The SST fields are created using a combination of in-situ and satellite measurements. In this paper, several different stages of the production of HadISST version 1 (HadISST1) including Advanced Very High Resolution Radiometer (AVHRR) data are compared against HadISST1 including data from the Along-Track Scanning Radiometer (ATSR) series in place of AVHRR data in equivalent stages of its production, and an independent source of sea surface temperature data.

The AVHRR bias correction during 1998 has a cooling effect on the initial HadISST1 analyses (those consisting of just in-situ data) with a few areas of exception, whilst the ATSR-2 bias correction has both regions of positive and negative influence. Bias corrections from both instruments cause the analyses compiled using the different instruments to be more similar. However one particular difficult area with disagreements is the North Pacific. Significant areas where the ATSR-2 analyses are cooler than those for AVHRR are the Gulf Stream, around the Falklands and the North Pacific. The TMI SSTs support the ATSR-2 results in several regions, significantly, to the West of Africa, which is a region affected by Saharan dust plumes, showing the ATSR-2 retrieved SSTs are not noticeable affected. Other regions where TMI SSTs support the ATSR-2 results are around the Falklands region in the South Atlantic and along the coastline of Eastern USA concluding that the analyses using ATSR-2 have areas of improvement over those using AVHRR, but there are also areas which are less conclusive. The analyses show extensive differences between the bias-corrected ATSR-2 and AVHRR versions of HadISST, which may be realistic, however it should be reviewed whether a different bias correction method should be tried in the next version of HadISST.

The HadISST1 product which includes AATSR data differs little from that which includes AVHRR data in 2003 on a global scale. However, regional differences between AATSR and AVHRR analyses of monthly mean SST often differ by the order of 1K, leading to differences between the two versions of HadISST1. The southern Atlantic Ocean is perhaps the most successful region for AATSR, particularly close to Africa, where seasonal differences between the AATSR and AVHRR products and the corresponding measurements of SST by TMI suggest AATSR is more accurate than AVHRR in this region. AATSR also appears to have a positive impact in the Gulf Stream, SW Pacific and western Indian Ocean in many months of

2003. The North and tropical East Pacific are perhaps the least successful region for AATSR since TMI measurements over this region are consistently closer to the AVHRR HadISST product than that including AATSR. Further differences between AATSR and AVHRR HadISST1 products exist regionally at latitudes North of 40N and South of 40S, which are sparsely covered by in-situ or validation data. The addition of the in-situ blending step has the effect of reducing the bias in areas which are well covered by in-situ data, see for example the North Atlantic and North Pacific in February 2003 and it generally reduces the bias in other regions.

Plans are in place to use AATSR SST data in the next version of HadISST called HadISST2 which is due to come on stream in early 2006. It will also be possible to utilise ATSR-2 SST data in HadISST2 to produce the final fields, a limitation of HadISST1, as different in situ fields will be used. Presently the unavailability of all in-situ fields for 1998 disables the ability to produce final versions of HadISST1 using ATSR-2 data.

1. Introduction

The HadISST1 analyses are traditionally compiled from a blend of in-situ data and SSTs retrieved from the AVHRR instrument upon the National Oceanic and Atmospheric Administration (NOAA) series of polar-orbiting satellites (see Rayner *et. al,* 2003 for more details). The (A)ATSR instruments on the European Space Agencys (ESA) European Remote Sensing (ERS) and Envisat polar-orbiting satellites are specifically designed for climate SST monitoring and aim to provide highly accurate SSTs to within 0.3K accuracy. Using comparisons between the HadISST1 analyses derived using (A)ATSR and those derived using AVHRR, in addition to comparisons between different versions of HadISST1 compiled in slightly different ways, we analyse the difference that the inclusion of bias corrected and non-bias corrected AVHRR and (A)ATSR data, with and without a final in-situ blending step, have on the HadISST1 datasets. We also compare these analyses to SST measurements from the independent Tropical Rainfall Monitoring Mission (TRMM) Microwave Imager (TMI). We discuss these findings in making an assessment of the impact of (A)ATSR data on HadISST1.

2. Data types

2.1 HadISST1

HadISST1 (Rayner *et. al*, 2003) is an analysis of monthly mean SST from 1871 to date, developed at the Hadley Centre for the main purposes of forcing atmospheric global climate models (AGCMs) in the simulation of recent climate and the evaluation of coupled atmosphere-ocean models. It aims to preserve real climate signals on global, ocean-basin and sub-regional scales, while minimising random errors, sampling noise and systematic biases. For these purposes, it has been made globally complete.

The in-situ data in HadISST1 are received through a combination of individual ship and buoy reports, on the Global Telecommunications System (GTS) and the Comprehensive Ocean-Atmosphere Data Set (COADS) [Woodruff, 1987]. However, the in-situ data do not cover the entire ocean for any single month, therefore satellite-based SSTs are included when available to provide input observational coverage which, in recent years, is almost globally complete.

The in-situ data are averaged and interpolated into a globally complete field, using reduced space optimal interpolation (RSOI) [Kaplan et. al, 1997]. This field is then used to correct satellite-based SST data, for the purpose of removing biases, before its inclusion in HadISST1. These biases include the residual differences between skin and bulk SSTs and contamination by undetected aerosol and clouds. Subtracting a night-time (in the case of AVHRR) satellite-based SST field from the in-situ SST field, the difference can be smoothed to

create a correction field, which is then added to the satellite SST field. In some of the analyses which follow, the satellite-based SST field can be left without correction, but this is not usual in HadISST1.

The satellite and in-situ fields are then averaged together and reconstructed as a 2° spatial resolution anomaly field. To make HadISST1 globally complete, while aiming to reconstruct the global pattern of long term change and residual inter-annual variability, the gaps in the combined in-situ/satellite SST data are filled by RSOI, as described for the in-situ data above. As an extra step, the reconstruction can be augmented by blending the analysis with variance-corrected in-situ data. A sea ice concentration field is collated separately and added to the SST field to produce the HadISST1 analysis. This is then added to the 1° background climatology to produce globally complete 1° fields.

2.2 AVHRR

AVHRR has an instantaneous field of view of 1.1km which scans across the swath perpendicular to the ground track of the satellite, whose orbit is sun-synchronous. It has two visible channels (channels 1 and 2 at 0.6 and 0.9 μm, respectively), one short-wavelength infrared channel (channel 3 at 3.7 μm), and two long-wavelength infrared channels (channels 4 and 5 at 11 and 12 μm, respectively). The wavelengths of the three infrared channels are in a range of the electromagnetic spectrum in which absorption by all atmospheric gases is weak, although any absorption, and re-emission of radiation by atmospheric gases, must be corrected for. From the channel 3, 4 and 5 radiances, brightness temperatures can be inferred which are used to calculate SST [Pichel, 1991].

In the cases where clouds obscure the surface, AVHRR measures radiation from cloud tops. In these cases, the temperatures retrieved are usually too low and thus usually readily detected and rejected. Sea ice in the field of view may also cause a cold bias, and aerosols such as Saharan dust can also bias AVHRR SSTs. Night-time AVHRR retrievals are used in HadISST as their biases are more easily removed than those in daytime retrievals, which are affected by reflected solar radiation (in channel 3) and diurnal warming of the sea surface. The correction step using fields of in-situ data, as described in Section 2.1, is an attempt to remove the biases in night-time SSTs from satellite-based sources such as AVHRR for use in HadISST1.

AVHRR was originally chosen as the satellite-based source of SST data in HadISST1, due to its greater coverage and longer record than (A)ATSR. AVHRR measures top-of-the-atmosphere radiances and then SSTs are retrieved using algorithms which have been tuned by regression of brightness temperatures from the instrument's infrared channels onto in-situ SST data from a set of drifting buoys. Thus, AVHRR SSTs are equivalent to measurements of the bulk surface temperature of the sea (bulk SST), which is the temperature at equivalent depths to those at which the in-situ measurements are taken and at which the HadISST1 analyses aim to represent.

The AVHRR data supplied for use in HadISST1 takes the form of monthly means of night-time SST of area 1° in latitude by 1° in longitude. The monthly means are calculated by taking averages of weekly observations for all weeks falling totally, or for the most part, within the target month.

2.3 ATSR-2 and AATSR

The Along Track Scanning Radiometer (ATSR) has to date been flown on three satellite missions, ATSR-1 on ERS-1 (1991-1995), ATSR-2 on ERS-2 (1995-present) and the Advanced Along Track Scanning Radiometer, AATSR, on ENVISAT (2002-present). Each instrument has

3 infrared channels centred in the atmospheric windows at 3.7μm, 10.8μm and 12.0μm plus channels in the visible/near infrared part of the spectrum used for cloud detection. The ATSR series of instruments are designed to retrieve SST to better than 0.3K accuracy in the derived skin SST and give a long-term stability of better than 0.1K. More details on the ATSR instrument design and performance in retrieving SST can be found in Mutlow *et.al.* (1999). ATSR has an inclined conical scan which enables it to make observations of the surface from two different angles, nadir and a forward view (~55°), within a few minutes of each other, allowing better correction for atmospheric absorption and aerosols than AVHRR, producing highly accurate SST retrievals.

This study used 10 arc minute spatially averaged 'skin' SSTs derived from ATSR-2 top of atmosphere brightness temperatures from January to December 1998 and AATSR data from January to December 2003. These skin SSTs have been converted to a pseudo 'bulk' SST. (See O'Carroll *et.al.* (2003, 2004) for more details on this conversion). The bulk SST is representative of the ocean temperature at around 1 metre in depth and is a better measure of the overall heat capacity of the ocean. HadISST1 is compiled from in-situ and AVHRR observations representative of a similar depth to the (A)ATSR 'bulk' SSTs.

2.4 TRMM Microwave Imager

The Tropical Rainfall Monitoring Mission (TRMM) is a joint NASA and NASDA mission, which was launched in November 1997. The TRMM orbit moves from west to east providing data at varying local times between 40°S and 40°N. On board TRMM is the TRMM Microwave Imager (TMI), which is a conical scan microwave radiometer with channels at five separate frequencies: 10.7, 19.4, 21.3, 37 and 85.5GHz and a spatial resolution of about 50km. A combination of channels [Wentz *et. al.,* 2003] are used to retrieve SST through clouds, which are nearly transparent at 10.7GHz. As microwave channels are less sensitive to water vapour and cloud, so ocean and persistently cloudy coverage can be viewed more often than with infrared sensors. These TMI SSTs provide an ideal dataset against which to compare the various HadISST1 analyses presented here in the sub-tropics/tropical regions.

The TMI SST product we have used is downloadable direct from the Remote Systems Website http://www.ssmi.com/ as daily, weekly and monthly averages and is available from December 1997 between -40 and +40 degrees latitude. We have used the daily averaged data processed with version 3a. These daily TMI means at a quarter of a degree spatial resolution are then averaged to monthly one degree cells and compared with the various versions of HadISST. Wentz *et. al.,*2003, contains information on the TMI SST retrieval algorithm.

3. Methodology

3.1 Production of HadISST1-type analyses

The in-situ ship and buoy data received through individual ship reports and the GTS for inclusion in HadISST1 were compiled in the Met Office Marine Data Bank (MDB). These data are collected using a variety of different methods, therefore they must be quality controlled to remove outliers. Bias corrections are not applied to the most recent in-situ data used in HadISST1. The aim of quality control is to remove data which is wrongly positioned, outside reasonable limits or significantly different from its nearest neighbours. For HadISST1, the in-situ data is initially quality controlled by the methods used for the Met Office Historical SST Version 6 (MOHSST6) data set [Bottomley (1990), Parker (1995)] and constructed as a 1° latitude-longitude field, with gaps filled, where possible, by data from COADS. This is hereafter referred to as the original MDB/COADS SST field.

The original MDB/COADS SSTs are re-gridded into a 2º latitude-longitude grid. This blended in-situ field is then subject to further quality control to remove any remaining outliers (see Rayner *et. al* (2003) for details). Once all grid boxes have been checked against their neighbours, RSOI is used to reconstruct the SST anomalies as a 2º latitude-longitude field. This reconstructed field is blended with the original MDB/COADS 2º latitude-longitude SST field to reintroduce localised variability in the complete in-situ SST field.

These complete in-situ SST fields can be used to correct satellite-based SST data, for the purpose of removing biases as described in Section 2.1. The 1º latitude-longitude satellite-based SST field can be subtracted from the complete in-situ field, and the difference smoothed, to create a correction field which can then be added to the satellite SST field. In HadISST1, this is always applied, but in the analyses presented here, it is sometimes not to illustrate its effect.

The satellite SST anomaly field, whether bias corrected or not, is averaged with the in-situ field onto a 2º latitude by 2º longitude grid, which is in turn subjected to neighbour-based quality controls as described for the 2º latitude by 2º longitude grid of MDB/COADS SST above. At this point RSOI is used again to reconstruct this average as a globally complete 2º latitude-longitude analysis, the 1º background climatology and the sea ice concentration field are added to produce 1º fields of SST.

In HadISST1, an extra step is included, in which this analysis is blended with variance corrected in-situ SST anomalies, to reintroduce localised variability in the final HadISST1 field, (see Rayner *et. al* (2003) for more details). However, in some of the analyses presented here, this step is not done to illustrate its effect.

This paper refers to eight different versions of HadISST1 analyses, defined and named as A to H in Table 1. (A)ATSR is the satellite data source in A to D. The in-situ blending step is included in the 2003 analyses only, so we assess 12 sets of fields in total.

Table 1. Definition of types of HadISST1 product.

Name	**Satellite SST source**	**Bias correction step**	**Final in-situ blending step**
A	**AATSR (2003)**	Included	Included
B	**AATSR (2003)**	Not included	Included
C	**ATSR-2 (1998)** **AATSR (2003)**	Included	Not Included
D	**ATSR-2 (1998)** **AATSR (2003)**	Not included	Not Included
E	**AVHRR (2003)**	Included	Included
F	**AVHRR (2003)**	Not included	Included
G	**AVHRR (1998,2003)**	Included	Not Included
H	**AVHRR (1998,2003)**	Not included	Not Included

3.2 Comparison of HadISST1-type analyses

Comparisons between the versions of HadISST1 as listed in Table 1 have been made to analyse the impact of (A)ATSR data in HadISST1, and to discuss what difference including bias-corrected and un bias-corrected AVHRR and (A)ATSR data has on the HadISST1 dataset. Note that HadISST analyses using ATSR-2 for 1998 using the in situ blending step were not available, which has limited the 1998 analysis to look at the effect of the bias correction step only.

The first set of comparisons analyse the effect that the satellite bias correction step, as applied to (A)ATSR and AVHRR data, has on the HadISST1 product. Specifically, version A fields are compared to B and C to D to assess the effect on (A)ATSR. Similarly, for the AVHRR comparisons, version E fields are compared to F, and G to H.

Secondly, analyses are performed to analyse what effect the in-situ blending step has on the HadISST1 versions, both when the bias correction is not applied and when it is applied. Specifically, products A are compared to products C, and B to D, for (A)ATSR. Similarly, for the AVHRR comparisons, products E are compared to products G, and F to H.

The third comparisons to be performed are to compare the HadISST1 products using assimilated (A)ATSR data with those products using AVHRR data. For these analyses, products A-D are compared with products E-H in sequence. This set of comparisons more clearly summarises the actual effect of including (A)ATSR data rather than AVHRR in HadISST1.

3.3 Comparison of HadISST1 versions to independent data

Monthly TMI SST data from 1998 and 2003 are compared to each HadISST1. Areally averaged statistics between each two sets of fields between ±40° latitude are produced and analysed. It should be noted that whilst the HadISST1 analyses are representative of a bulk ocean temperature, the TMI SSTs represent a temperature just beneath the ocean skin.

4. Results

The results are presented in sections dependent on the comparison being performed. For ease of reference figures for only four months per year studied have been included within this report (appended to the end). For 1998, figures have been included for January, April, July and November. For 2003, figures have been included for February, May, August and November.

4.1 Comparing HadISST1 versions with/without satellite bias corrections

HadISST (corrected ATSR-2) minus HadISST (uncorrected ATSR-2), 1998, no in situ blending (figures 1a, 2a, 3a, 4a):
Global average differences between these analyses throughout 1998 vary between -0.1K and 0.1K. The corrected products are warmer than the uncorrected in the western Southern Hemisphere, reaching up to 1.5K warmer around the Falklands. The corrected fields are warmer around the Gulf Stream from January-April and in December 1998, but in other parts of the North Atlantic the corrected fields are cooler than the uncorrected (by 1.5K). Standard deviations of the differences vary from ~0.2K to a maximum of ~0.36K from March to May 1998.

HadISST (corrected AVHRR) minus HadISST (uncorrected AVHRR), 1998, no in situ blending (figures 1b, 2b, 3b, 4b):
Global average differences between these analyses, vary between 0.12 to 0.3K. The corrected products are warmer than the uncorrected in large parts of the globe, often around 0.3K. The corrected fields are cooler around the Gulf Stream and the North Pacific from March- June 1998. However, the corrected fields are warmer in the mid-Atlantic up to 1.5K for most of the year. Standard deviations increase to a maximum in Northern Hemisphere summer at around 0.38K, falling sharply in September 1998.

HadISST (corrected AATSR) minus HadISST (uncorrected AATSR), 2003, no in situ blending (figures 5a, 6a, 7a, 8a):
The monthly global average difference between these analyses varies between 0.04K in January to a minimum of -0.09K in August 2003. Within the Mid-SE Pacific, the corrected analyses are consistently warmer than the uncorrected analyses, especially in the Tropical regions. Additionally, the corrected field is also warmer in the South Atlantic from April onwards. The corrected analyses are generally cooler than the uncorrected, in the North-East Pacific and North Atlantic, more so in July and August. The global standard deviation of the differences is lowest in January and February when the corrected field is warmer than the uncorrected, and highest in the northern hemisphere summer.

HadISST (corrected AVHRR) minus HadISST (uncorrected AVHRR), 2003, no in situ blending (figures 5b, 6b, 7b, 8b):
The monthly global mean difference between these analyses varies from 0.06K in May to a minimum of -0.06K in August. These differences are very similar to those seen for AATSR above, except the corrected analyses using AATSR are cooler than those for AVHRR in the North Pacific and North Atlantic in July. The global standard deviation is lowest in northern hemisphere winter and highest in northern hemisphere summer.

HadISST (corrected AATSR) minus HadISST (uncorrected AATSR), 2003, with in situ blending (figures 5c, 6c, 7c, 8c):
The monthly global mean difference between these analyses varies from 0.04K in May to a minimum of -0.04K in August. In the South Indian Ocean and to the South of Australia, the correction cools HadISST, particularly in UK spring months, while the correction has a cooling effect in the North Pacific and North Atlantic, particularly in UK summer months. The warming effect of the correction is greatest in the El Nino region and SE Pacific, although the North Indian Ocean and South Atlantic Ocean are markedly warmer after correction in most months.

The addition of the in-situ blending step has the effect of reducing the bias in areas which are well covered by in-situ data, see for example the North Atlantic and North Pacific in February 2003 and it generally reduces the bias in other regions, but the resultant fields appear more noisy.

HadISST (corrected AVHRR) minus HadISST (uncorrected AVHRR), 2003, with in situ blending (figures 5d, 6d, 7d, 8d):
The monthly global mean difference between these analyses varies from 0.04K in May to -0.04K in July. The correction has a similar cooling effect to AATSR close to UK spring months in the South Indian Ocean and to the South of Australia, and close to UK summer months in the North Pacific. The North Atlantic is cooled by the correction to AVHRR in August to October, but in other months it is generally warmed by the correction, especially to the NW of Africa, which is in contrast to AATSR. Warming is seen again in the Tropical Pacific, the mid-South Pacific, North Indian and SE Atlantic, but the Falklands and West of Chile are generally cooled by the correction to AVHRR, especially in the UK summer months to a greater extent than AATSR.

Summary:
The AVHRR bias correction for 1998 consistently warms the version of HadISST containing AVHRR data, except for in small regions in some months e.g. Gulf Stream, North Pacific and around the Falklands. The ATSR-2 bias correction has a warming effect in the Western-Southern Hemisphere, around the Falklands region in the South Atlantic and the Gulf Stream. However, it has a cooling effect in the mid-Atlantic.

The corrected fields are almost consistently warmer than the corresponding uncorrected fields in the mid-SE Pacific region, particularly in the Tropical (El Nino) region, and are almost consistently cooler in the North Pacific for both satellites. However, the effect of the correction differs between the two satellites in some regions, in particular the Falklands region, where generally the correction procedure warms HadISST including AATSR but cools the analyses which include AVHRR. Variation can also be seen in the Atlantic off the coast of NW Africa, where for much of the year the correction cools the product including AATSR, but warms the product including AVHRR.

4.2 Comparing HadISST1 versions with/without final in situ blending step

HadISST (with in situ blending) minus HadISST (no in situ blending), corrected AATSR,2003 (figures 9a, 10a, 11a, 12a):
The monthly mean difference between these analyses is always positive throughout 2003, where the in situ blended step is warmer, peaking in August where the mean difference is ~0.65K. There are large areas of the plots where there is ~zero difference between the plots, the rest of the difference plots being quite blotchy where the insitu blended results are warmer than the non-in situ blended results, and vice versa. Areas where patterns emerge include the Gulf Stream where the in situ blended is warmer than the non-in situ blended, the Tropical Pacific where the with in situ blended results are cooler than the non-in situ blended results, and the North Pacific where the with in situ blended are warmer.

HadISST (with in situ blending) minus HadISST (no in situ blending), uncorrected AATSR, 2003 (figures 9b, 10b, 11b, 12b):
These uncorrected analyses show similar results to the corrected summarised in the previous paragraph, however the plots are slightly more blotchy. The with in situ blended results are again warmer than the non in situ blended results, which peaks at a ~0.04K monthly difference in October 2003. The with in situ blended results still show to be warmer in the Gulf Stream than the non in situ blended results, less so in the Tropical and North Pacific.

HadISST (with in situ blending) minus HadISST (no in situ blending), corrected AVHRR, 2003 (figures 9c, 10c, 11c, 12c):
The with insitu blended analyses for corrected AVHRR in HadISST are always warmer than the non in situ blended results, up to a maximum of 0.06K monthly difference in August 2003. The with in situ blended results shows a similar impact to the AATSR difference plots, with similar patterns emerging in the Gulf Stream and Tropical Pacific as already discussed.

HadISST (with in situ blending) minus HadISST (no in situ blending), uncorrected AVHRR, 2003 (figures 9d, 10d, 11d, 12d):
These difference plots with uncorrected AVHRR in HadISST show that the with in situ blended results are warmer than the non in situ blended results, and that this difference increases throughout the year, with an interim maximum in April 2003. The monthly difference plots show similar results to the corrected AVHRR in HadISST.

Summary:
The plots of with in situ blended AATSR and AVHRR in HadISST minus the non in situ blended results show that for all cases there are large areas of zero difference between the plots, but blotchy areas of warmer and cooler with in situ blended. In general the in situ blended step is warming the satellite based HadISST analyses (whether or not they have been bias corrected). Additional comparisons of corrected minus uncorrected analyses with in situ blending presented in section 4.2 show that the addition of the in situ blending step has the effect of reducing the bias in areas which are well covered by in situ data for

example in the North Atlantic and North Pacific in February 2003 and generally reduces the bias in other regions.

4.3 Comparing HadISST1 versions using AVHRR and (A)ATSR

HadISST (uncorrected ATSR-2) minus HadISST (uncorrected AVHRR), 1998, no insitu blending (figures 1d, 2d, 3d, 4d):
The monthly global average differences between these two analyses during 1998 vary between 0.05K and 0.45K with lots of spatial variation, with standard deviations between the two analyses reaching a maximum in summer at 0.65K in July. Even given the wide variation in the differences over the globe, generally these differences are within ±0.4K with the exception of a few features which are up to ±1.5K. These features are described in full in section 5.1. However, in brief, the North Pacific, Gulf Stream and around the Falklands are regions where the HadISST1 analyses compiled using ATSR-2 are cooler than those using AVHRR. In the Mid-Atlantic the HadISST1 analyses using AVHRR are warmer.

HadISST (corrected ATSR-2) minus HadISST (corrected AVHRR), 1998, no in situ blending (figures 1c, 2c, 3c, 4c):
Similar to the uncorrected differences described in the previous paragraph, there are lots of differences between these plots where the monthly differences vary between -0.1K to 0.15K. Similar features exist as for the uncorrected difference plots, but the amplitudes are of a smaller scale as the bias-correction step converges the results.

HadISST (uncorrected AATSR) minus HadISST (uncorrected AVHRR), 2003, no in situ blending (13a, 14a, 15a, 16a):
The monthly mean difference between these analyses varies between -0.04K (July) to 0.04K (April), where the uncorrected AATSR HadISST1 analyses are warmer than those for uncorrected AVHRR in April, May and December 2003 only. The analyses using AATSR are warmer in the tropical Pacific as well as to the North-West of Africa and to the West of the U.S. This may be an indication of better AATSR retrievals over regions known to be affected by aerosols. In the Southern Indian Ocean, the analyses using uncorrected AATSR are also generally warmer than those using uncorrected AVHRR, especially in northern hemisphere winter. The HadISST1 analyses using uncorrected AVHRR are generally warmer than those using AATSR around the Falklands, South Pacific and the Bering Sea. The global standard deviation of the differences is lowest in October and highest in July.

HadISST (corrected AATSR) minus HadISST (corrected AVHRR), 2003, no in situ blending (figures 13b, 14b, 15b, 16b):
The monthly mean difference between these analyses varies from -0.03K (July) to -0.01K (February) where the HadISST analyses using corrected AVHRR are always warmer than those using corrected AATSR. However, in the tropical Pacific the analyses using AATSR are much warmer than those for AVHRR. Features where the analyses using AVHRR are much warmer than those using AATSR occur in the Atlantic: to the East of Canada, and the Falklands.

HadISST (uncorrected AATSR) minus HadISST (uncorrected AVHRR), 2003, with in situ blending (13c, 14c, 15c, 16c):
The monthly mean difference between these analyses varies from 0.02K in April to a minimum of -0.04K in July. April and December are the only months when the global mean difference is positive: the AATSR analyses being warmer in the Tropical Pacific, mid-North Atlantic, Indian Ocean and close to Australia. However, South Pacific is cooler for AATSR, particularly close to UK summer, as is most of the South Atlantic, with the exception being SW of Africa in UK winter months. The North Pacific is consistently slightly cooler for the AATSR analyses.

HadISST (corrected AATSR) minus HadISST (corrected AVHRR), 2003, with in situ blending (13d, 14d, 15d, 16d):
After applying the correction, the mean difference between these analyses sees AATSR cooler than AVHRR every month, varying between -0.01K and -0.02K, with the greatest difference in August. This may be attributed mainly to the Falklands region, although SW Pacific is also generally cooler for AATSR. Other regions vary strongly: AATSR is warmer in the Tropical Pacific region, especially in Northern Hemisphere spring months, but cooler in January. AATSR is warmer throughout most of the Indian Ocean. North Atlantic and North Pacific are generally in good agreement, with variations in a few small regions particularly in Northern Hemisphere summer months.

Summary:
The uncorrected ATSR-2 HadISST1 versions are cooler than the corrected AVHRR during 1998 around the Gulf Stream, Falklands, and North Pacific (for some months). However, there are also areas where ATSR-2 is much warmer than the AVHRR analyses, up to 1.5K, especially in the Mid-Atlantic. Analyses of April 1998 (figure 2d), show that the area where ATSR-2 is warm extends to a much larger area, including most of the Northern Hemisphere, and around Australia.

After the bias correction step has been applied to the HadISST analyses using ATSR-2 and AVHRR data the differences between the analyses using the two instruments are much smaller. The same signals can still be seen as for the uncorrected analyses, but the amplitudes are much smaller. This signals that the bias correction step causes the HadISST analyses using ATSR-2 and AVHRR to be more similar, but is not removing the largest difference features fully suggesting perhaps a different bias correction method should be tried in the next version of HadISST. The ATSR-2 analyses have the largest corrections in the mid-Atlantic (cooling the product), whilst in the Falklands region the ATSR-2 correction has a warming effect. It is not conclusive in the North Pacific which instrument has the largest influence, as both vary throughout the year.

After correction, the global mean difference between the HadISST analyses (AATSR-AVHRR) is negative. The uncorrected analyses show the AATSR product to be generally warmer than the AVHRR product in the Tropical (El Nino) Pacific region, as well as in the mid-East Atlantic and South Indian Ocean. The AVHRR product is generally warmer than the AATSR product in the Falklands, and South Pacific, particularly after correction. The greatest annual variation can be seen in the South Atlantic. The difference between the 1998 and 2003 plots shows that one of the satellite instruments is performing much better in 2003 due to the smaller differences – perhaps AVHRR.

4.4 Comparison of HadISST1 versions (including bias corrected satellite data) with independent data.

Various HadISST1 analyses have been compared with TMI data for three months in 1998 and three months in 2003.

Comparing TMI minus HadISST (uncorrected/corrected ATSR-2) with TMI minus HadISST (uncorrected/corrected AVHRR), 1998, no insitu blending (figures 17a-c, 18a-c):
During January, the difference analyses are very similar, however, in the Atlantic the HadISST1 analyses using ATSR-2 are closer to TMI than those using AVHRR. The April and July results are similar but with some differences in amplitudes in the North Atlantic. For April, in the North Atlantic, HadISST using ATSR-2 is cooler than TMI and also similar

patterns can be seen to the West. In the North Pacific HadISST1 using ATSR-2 is cooler than HadISST with AVHRR. Both the plots using corrected and uncorrected ATSR-2/AVHRR are similar. The corrected plots for ATSR-2 and AVHRR are shown in figures 17a to 17c and 18a to 18c respectively. Table 2 below gives the statistics of the differences between TMI and the HadISST1 analyses. Larger mean differences are seen between TMI and the uncorrected AVHRR in HadISST then the corrected AVHRR in HadISST, expected due to the observed general warming effect of the AVHRR bias correction in 1998. The differences between TMI and HadISST1 are much greater than between (A)ATSR/AVHRR and HadISST1 which means that TMI has large biases which also makes it not ideal for independent validation.

Table 2. Statistics of TMI – HadISST1 differences, for 1998.

	Mean (K)	Stan. Dev	Num pts.	Mean (K)	Stan. Dev	Num pts.
	TMI – HadISST1 (corrected ATSR-2)			TMI – HadISST1 (corrected AVHRR)		
Jan 1998	0.14	0.74	19971	0.15	0.74	19971
Apr 1998	0.04	0.74	19966	0.18	0.76	19966
Jul 1998	0.16	0.78	19966	0.19	0.76	19966
	TMI – HadISST1 (uncorrected ATSR-2)			TMI-HadISST1 (uncorrected AVHRR)		
Jan 1998	0.20	0.82	19971	0.31	0.78	19971
Apr 1998	-0.02	0.85	19966	0.50	0.76	19966
Jul 1998	0.19	0.86	19966	0.56	0.82	19966

Comparing TMI minus HadISST (uncorrected/corrected AATSR) with TMI minus HadISST (uncorrected/corrected AVHRR), 2003, with insitu blending

Comparisons of the TMI – HadISST difference plots, where ATSR-2 and AVHRR have been used in figures 19a to c and figures 20a to c respectively, show very similar plots, which is reinforced by the statistics in Table 3 below. Areas of large differences do occur in the comparisons of HadISST1 with TMI SSTs. For most months the TMI SST is cooler than HadISST1 along the equatorial Pacific, which is especially noticeable in May 2003. The plots for April and August 2003 show that TMI is warmer than HadISST1 over a large area, whereas TMI is cooler in the North Pacific. It should be emphasised that the uncorrected HadISST1 using (A)ATSR are closer to TMI than HadISST1 using AVHRR in nearly all cases.

Table 3. Statistics of TMI – HadISST1 differences (with in-situ blending), for 2003.

	Mean (K)	Stan. Dev	Num pts.	Mean (K)	Stan. Dev	Num pts.
	TMI – HadISST1 (corrected AATSR)			TMI – HadISST1 (corrected AVHRR)		
Feb 2003	0.10	0.70	20143	0.10	0.69	20143
May 2003	0.12	0.77	20154	0.12	0.76	20154
Aug 2003	0.29	0.67	20149	0.28	0.66	20149
	TMI – HadISST1 (uncorrected AATSR)			TMI – HadISST1 (uncorrected AVHRR)		
Feb 2003	0.12	0.69	20143	0.11	0.67	20143
May 2003	0.13	0.82	20154	0.21	0.72	20154
Aug 2003	0.27	0.69	20149	0.28	0.66	20149

4.5 Discussion

From the comparisons, between different versions of HadISST for both AATSR and AVHRR, regions of large monthly mean differences can be identified as regions where the satellite data is making a large impact in the final product. Where the uncorrected SST is higher than the corrected SST, the satellite data can be seen to be warming HadISST, and where the

uncorrected SST is lower than the corrected SST (in figures 5 to 8), the satellite data can be seen to be cooling HadISST. This is due to the behaviour that a bias correction created by warmer in-situ data than satellite data will be warmer than the satellite data, but cooler than the 1st analysis of HadISST (using in-situ only data). Therefore during the discussion of warming HadISST patterns to follow, we are referring to the first in-situ only iteration of the HadISST analysis. Similarly, where the non in-situ blended SST (in figures 9 to 12) is higher or lower than the in situ blended SST, the satellite data can be seen to be warming or cooling the initial HadISST version respectively.

The comparisons between TMI and HadISST after correction and in situ blending (in figures 19 to 20) can be used to validate the effect of the AATSR or AVHRR data. Where TMI is cooler than HadISST, the satellite data can be seen to have a positive impact if the correction step or in situ blending step warm the product, or a negative impact if the correction step or in situ blending step cool the product. However, since both these steps are included to improve the quality of the final HadISST product, the extent to which the satellite data warms or cools the final product is difficult to quantify, therefore such assessments are limited.

Comparisons between equivalent analyses containing AATSR and AVHRR (in figures 13 to 16) data can determine quantitatively the extent to which the two sources of satellite data warm or cool the product over the other. In this case, the comparisons between TMI and HadISST data (figures 19 to 20) can be used to validate whether the product including AATSR or AVHRR data is closer to the independent measurement of SST provided by TMI.

5. Regional analyses

Three specific global regions were identified as being of particular interest in the comparisons between the different HadISST1 versions: North Pacific (between 20 to 60 degrees latitude, and 130 and 180 degrees East), Falklands region in the South Atlantic adjacent to South America, and the Mid-Atlantic (between 10 and 50 degrees North, and 20 to 60 degrees East).

5.1 Regional analyses for 1998

North Pacific:
The HadISST1 analyses using ATSR-2 are cooler than those using AVHRR by up to 1.5K, seen as a striking round feature in the North Pacific for most months during the year (however, not from July to October). The feature is seen in both the corrected and uncorrected difference plots, as the bias correction step seems not to affect to a great extent the amplitude in either ATSR-2 or AVHRR compiled HadISST1 products. An example of this feature can be seen in the April analyses (figure 4d). The ATSR-2 bias correction varies throughout the year, but is usually between 0 and 0.3K. However, the AVHRR bias correction cools the AVHRR data slightly, but not enough to bring close to the ATSR-2 HadISST fields. The in-situ anomaly fields (figures 21a to 21d) are cooler in this region by ~1.5K. The variable ATSR-2 bias correction leads to variation whether the initial HadISST version (using insitu only) is warmed or cooled by the ATSR-2 data. However, the AVHRR bias correction cools HadISST in this region in January and July, but warms in April and November.

There are differing positive and negative patterns in the HadISST comparisons in figure 12, however TMI is always cooler than HadISST in this region, so it is not conclusive what effect ATSR-2 in the HadISST analyses is having in this region.

Falklands region:
The HadISST1 analyses with corrected ATSR-2 are much warmer in this region, up to 1.5K warmer, than those using uncorrected ATSR-2; whilst the HadISST1 analyses using AVHRR display small corrections in these regions (~±0.2K). Figures 1a, 2a, 3a, 4a, show that the HadISST analyses using uncorrected ATSR-2 are cooler than those using uncorrected AVHRR. The ATSR-2 bias correction (cooling initial HadISST) is making a larger effort to correct the ATSR-2/AVHRR differences than the AVHRR bias correction. There is very sparse in-situ data in this region, and so the satellite data is a major contributor to the HadISST1 analyses in these regions. AVHRR SSTs are derived from regression against buoy SSTs, which are sparsely populated in this region so the AVHRR retrievals may be deriving unrepresentative temperatures.

Comparisons against the TMI SSTs show that TMI is warmer than HadISST analyses in this region at around 30degrees South, and that TMI is cooler than the HadISST analyses at around 40 degrees South for the months shown in figures 17 and 18. These results correspond well with the pattern of HadISST analyses using ATSR-2 being warmer than HadISST using AVHRR in this region, therefore the TMI results support ATSR-2 as having a positive effect on the HadISST1 analyses.

Mid-Atlantic:
A large feature in the mid-Atlantic can be seen in the uncorrected HadISST analyses where the ATSR-2 analyses are warmer than those for AVHRR by up to 2K for most months during 1998, see figures 1a, 2a, 3a, 4a. The amplitude of these features is large and often coupled with a feature in the Gulf Stream where ATSR-2 is cooler than the AVHRR analyses.

Figures 1c, 2c, 3c, 4c show that the difference between the HadISST analyses with corrected ATSR-2 and those with corrected AVHRR have decreased. The features seen in figures 11a to 11d have decreased in amplitude with the bias correction step, and shifted slightly in position. The bias correction step for both instruments is attempting to correct for this difference. Small positive corrections are applied for AVHRR for most months, whilst the ATSR-2 corrections attempt to correct for the coupled pattern observed. However, in July and August, 1998, the amplitude of the AVHRR correction increases to up to 1.5K in most of the Atlantic with the exception of a negative correction in the Gulf Stream. Additionally for these months, the ATSR-2 correction is negative for the whole region. See figures 1a, 2a, 3a, 4a. To the East Atlantic near the African coast is often affected by maritime stratiform cloud which is difficult to detect in standard cloud-detection routines. This area is also affected by Saharan dust outbreaks. A combination of these factors may be leading the AVHRR SSTs to be too low.

The comparisons with TMI in this region (figures 17a to 17c) also display a similar coupled pattern, where TMI is warmer than both the ATSR-2 and AVHRR HadISST1 analyses, in the Gulf Stream, and cooler than HadISST1 in the mid-Atlantic.

Gulf Stream:
Whereas the main region of discussion referred to as the Gulf Stream in this paper has been to the South of the Labrador Sea where the ATSR-2 compiled HadISST has been seen to be cooler than those using AVHRR, we can see that around the coast of the Eastern US, the HadISST analyses using ATSR-2 are warmer than those for AVHRR. The ATSR-2 bias correction is cooling the initial in-situ only HadISST in this area, whilst the AVHRR bias correction varies throughout the year. We can see a similar feature in the TMI plots in figure 18, where TMI is warmer than HadISST (using AVHRR). Therefore using ATSR-2 in HadISST in this region has a positive effect.

East African coast:
It can been seen in figures 1d, 2d, 3d, 4d that the HadISST analyses using ATSR-2 are warmer than those for AVHRR in a plume feature to the West of Africa. This is likely to be due to Saharan dust cooling the AVHRR analyses, whilst ATSR-2 can cope with the dust due to its dual-view capabilities. The ATSR-2 bias correction strongly warms the initial in-situ only HadISST analyses, whilst the AVHRR bias correction cools. TMI is warmer than HadISST using AVHRR in this region too (figure 18), however figure 17 shows TMI more similar to HadISST using ATSR-2 here. TMI supports the ATSR-2 version of HadISST in this region, which is much better at coping with the aerosol outbreak than the AVHRR analyses.

5.2 Regional analyses for 2003

The Tropical region of the East Pacific appears (figures 5 to 8) as a region of high cooling by both sets of satellite data, but to a greater extent by AVHRR. Since TMI appears cooler than both products in this region, particularly in May 2003 (figure 19b, 20b), TMI supports the effect of both sets of satellite data here, especially AVHRR.

Satellite data appears to have little impact in the Pacific as a whole. In the North Pacific, the product is cooled by the bias correction for both AATSR and AVHRR (as seen in figures 5 to 8) and although it is generally warmed again by the in-situ blending step (as seen in figures 9 to 12), the net effect of both AATSR and AVHRR is to warm the final HadISST product, with the AATSR product slightly the warmer. However, TMI data in the North Pacific is generally cooler than HadISST (figures 19 to 20) so does not support AATSR or AVHRR here. Similarly, where AATSR and AVHRR appear to cool the HadISST product in the SE Pacific, TMI is warmer than HadISST. The SW of the Pacific near Australia is more successful, particularly for AATSR whose final product is generally warmer than AVHRR (figures 13 to 16) but cooler than TMI (figures 19 to 20). Both AATSR and AVHRR appear to warm the product in the southern hemisphere winter (figures 6 to 7), so AATSR is successful here.

In the North-East Atlantic Ocean, generally the product is cooled by the satellite data (figures 5 to 6), with an exception in August 2003 (figure 7). Here, TMI data is supportive in that it is cooler than the HadISST products in February and May 2003 (figures 19a, 19b, 20a, 20b), but warmer in August 2003 (figures 19c, 20c). It is hard to give either AATSR or AVHRR credit here, as the bias correction step makes the two varieties very similar here, with AATSR slightly the warmer (figures 13d, 14d). However, in the South Atlantic where the general pattern is for satellite data to cool HadISST (figures 6 to 8). TMI is warmer than HadISST and generally supports neither (figures 19b,19c,20b,20c). An exception can be found to the west of southern Africa, where TMI is cooler than HadISST, particularly in May and August 2003. A corresponding feature can be identified in comparisons of AATSR and AVHRR analyses (figures 14 to 15), where AATSR is the cooler product and thus appears more successful. Another exception is the Falklands, where AVHRR appears to warm HadISST (figures 5b,d to 8b,d, although this is outside the range which can be covered by TMI observations.

In the western Indian Ocean, the general pattern is that the satellite data cools HadISST slightly (figures 6 to 8), with February (figure 5) as a major exception. The corresponding AATSR and AVHRR analyses are very similar for most of the year (figures 14 to 16), but AATSR is the warmer product in February (figure 13) and as such is supported by the warmer TMI measurements (figures 19a, 20a). However, the cooling effect of both sets of satellite data in this region in May and August 2003 is not reflected in the TMI data (figures 19b,19c,20b,20c).

6. Conclusions and future work

The AVHRR bias correction during 1998 has a cooling effect on the initial HadISST1 analyses (those consisting of just in-situ data) with a few areas of exception, whilst the ATSR-2 bias correction has both regions of positive and negative influence. Bias corrections from both instruments cause the analyses compiled using the different instruments to be more similar. However one particular difficult area with disagreements is the North Pacific. Significant areas where the ATSR-2 analyses are cooler than those for AVHRR are the Gulf Stream, around the Falklands and the North Pacific. The TMI SSTs support the ATSR-2 results in several regions, significantly, to the West of Africa, which is a region affected by Saharan dust plumes, showing the ATSR-2 retrieved SSTs are not noticeable affected. Other regions where TMI SSTs support the ATSR-2 results are around the Falklands region in the South Atlantic and along the coastline of Eastern USA concluding that the analyses using ATSR-2 have areas of improvement over those using AVHRR, but there are also areas which are less conclusive. The analyses show extensive differences between the bias-corrected ATSR-2 and AVHRR versions of HadISST, which may be realistic, however it should be reviewed whether a different bias correction method should be tried in the next version of HadISST.

The HadISST1 product which includes AATSR data differs little from that which includes AVHRR data in 2003 on a global scale. However, regional differences between AATSR and AVHRR analyses of monthly mean SST often differ by the order of 1K, leading to differences between the two versions of HadISST1. The southern Atlantic Ocean is perhaps the most successful region for AATSR, particularly close to Africa, where seasonal differences between the AATSR and AVHRR products and the corresponding measurements of SST by TMI suggest AATSR is more accurate than AVHRR in this region. AATSR also appears to have a positive impact in the Gulf Stream, SW Pacific and western Indian Ocean in many months of 2003. The North and tropical East Pacific are perhaps the least successful region for AATSR since TMI measurements over this region are consistently closer to the AVHRR HadISST product than that including AATSR. Further differences between AATSR and AVHRR HadISST1 products exist regionally at latitudes North of 40N and South of 40S, which are sparsely covered by in-situ or validation data. The addition of the in-situ blending step has the effect of reducing the bias in areas which are well covered by in-situ data, see for example the North Atlantic and North Pacific in February 2003 and it generally reduces the bias in other regions.

Plans are in place to use AATSR SST data in the next version of HadISST called HadISST2 which is due to come on stream in early 2006. It will also be possible to utilise ATSR-2 SST data in HadISST2 to produce the final fields, a limitation of HadISST1, as different in situ fields will be used. Presently the unavailability of all in-situ fields for 1998 disables the ability to produce final versions of HadISST1 using ATSR-2 data.

7. References

Bottomley M, CK Folland, J Hsiung, RE Newell and DE Parker, 1990, Global Ocean Surface Temperature Atlas, *20+iv pp. and 313 colour plates, Her Majesty's Stn. Off., Norwich, UK*

Kaplan A, Y Kushnir, M Cane and M Blumenthal, 1997, Reduced space optimal analysis for historical data sets: 136 years of Atlantic sea surface temperatures*, J. Geophys. Res. 102, 27835-27860*

Mutlow CT, MJ Murray, DL Smith, PD Watts and P North, 1999, New datasets for climate change and land studies are on track, *EOS Trans AGU 80 (49) 589, 594-595*

O'Carroll AG, JG Watts, LA Horrocks, RW Saunders and NA Rayner, 2003, The first complete year of AATSR data production and validation, DEFRA report 4a0103

O'Carroll AG, RW Saunders, JG Watts and LA Horrocks, 2004, Reprocessing of the ATSR-2 Clear-Sea Consolidated Averaged Brightness temperature dataset to skin and bulk sea surface temperatures; including a cross-comparison with ATSR-1 SSTs from 1995, *DEFRA report 4a0203*

Rayner NA, DE Parker, EB Horton, CK Folland, LV Alexander, DP Rowell, EC Kent, A Kaplan, 2003, Global analyses of SST, sea ice and night marine air temperature since the late nineteenth century, *JGR Atmospheres 108, D14, 4407*

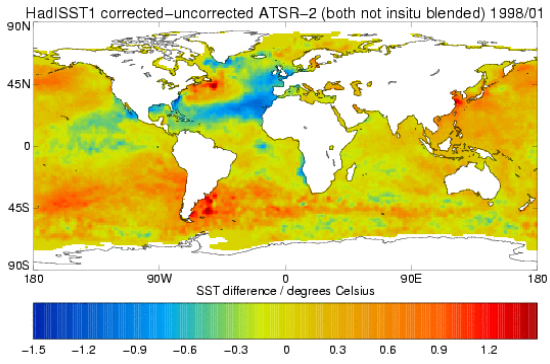
Parker DE, CK Folland and M Jackson, 1995, Marine surface temperature: observed variations and data requirements, *Clim. Change, 31, 559-600*

Pichel WG, 1991, Operational production of multichannel sea-surface temperatures from NOAA polar satellite AVHRR data, *Global and planetary change, 90 (1-3) 173-177*

Wentz F and T Meissner, 2000, ATBD Version 2 AMSR Ocean Algorithm. *RSS Tech. Proposal 121599A-1 available at:*
http://www.ssmi.com/papers/AMSR_Ocean_Algorithm_Version_2.pdf

Woodruff SD, RJ Slutz, RL Jenne and PM Steuer, 1987, A comprehensive ocean-atmosphere data set, *Bull. Am. Meteorol. Soc., 68, 1239-1250*

HadISST comparisons for 1998



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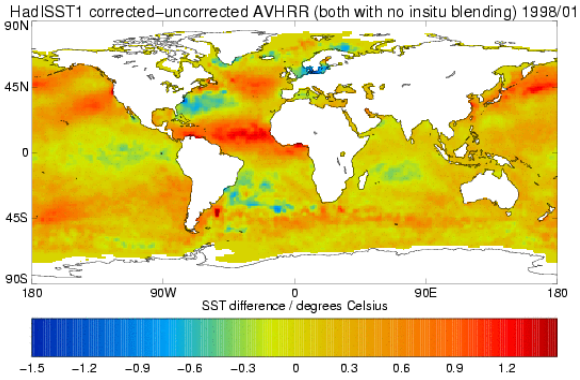

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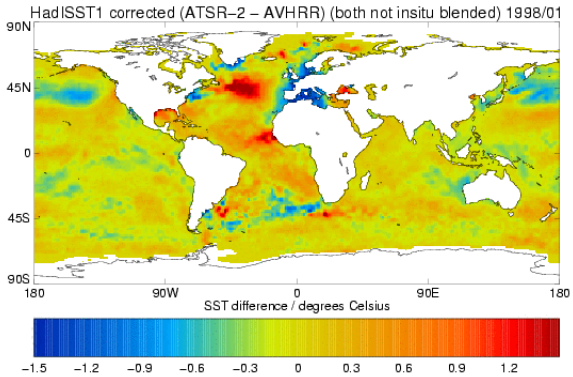

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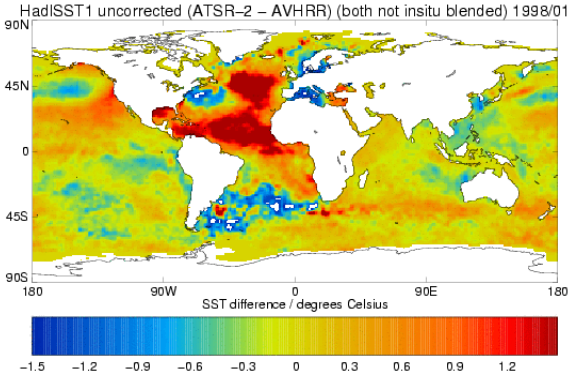

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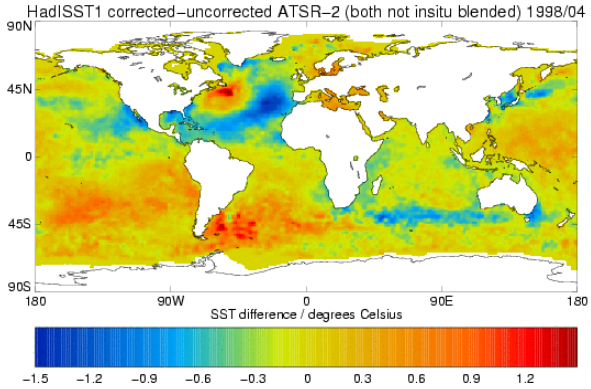
Figures 1a to 1d. Non-insitu blended results for January 1998



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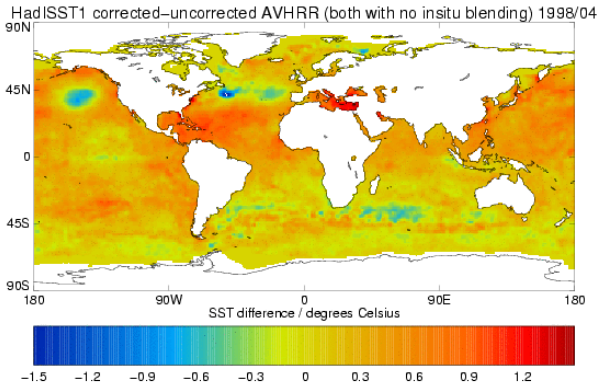

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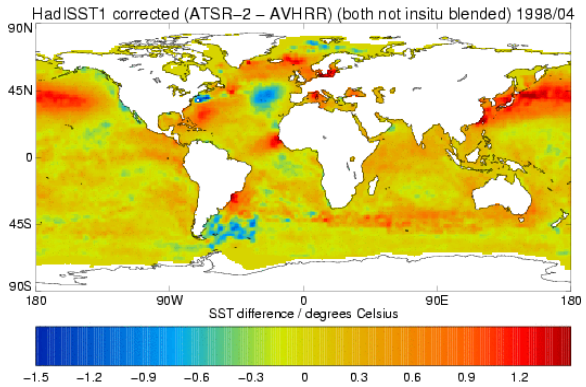

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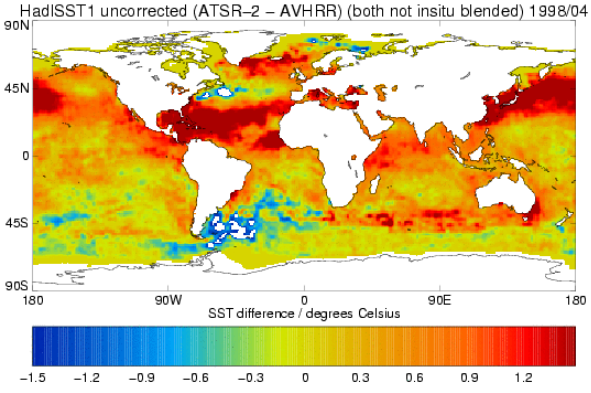

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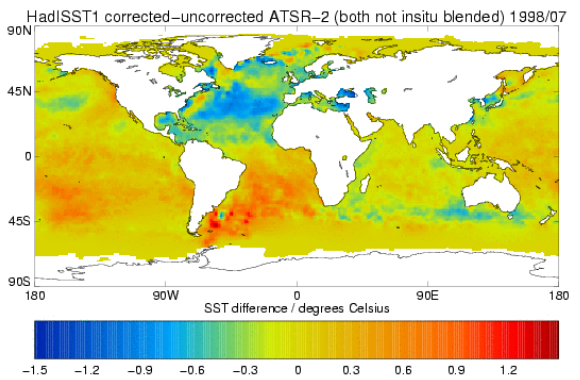
Figures 2a to 2d. Non-insitu blended results for April 1998



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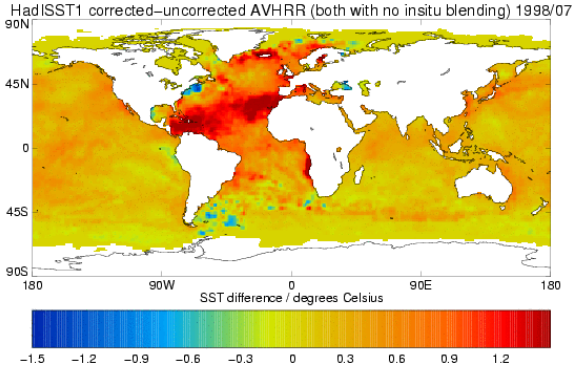

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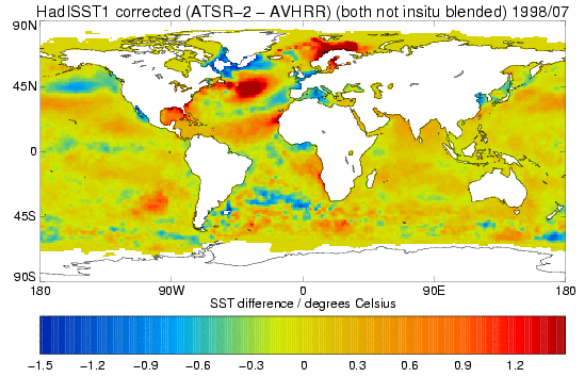

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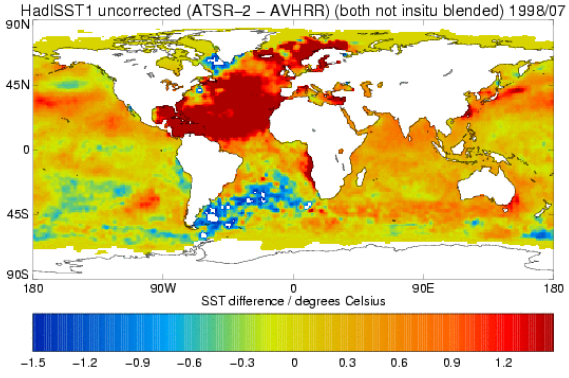

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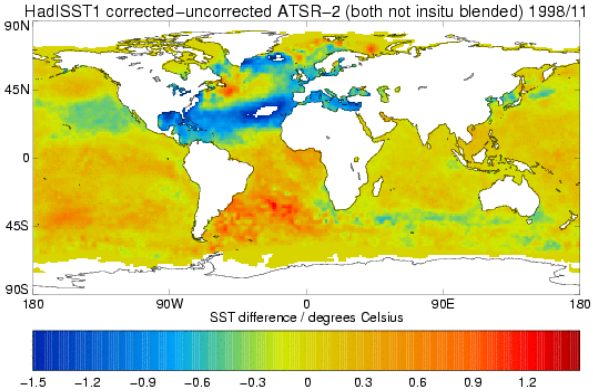
Figures 3a to 3d. Non-insitu blended results for July 1998



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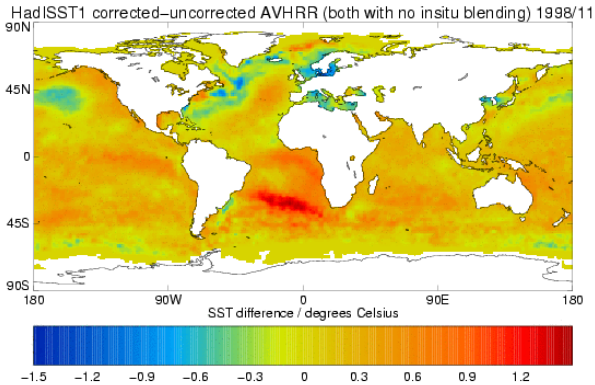

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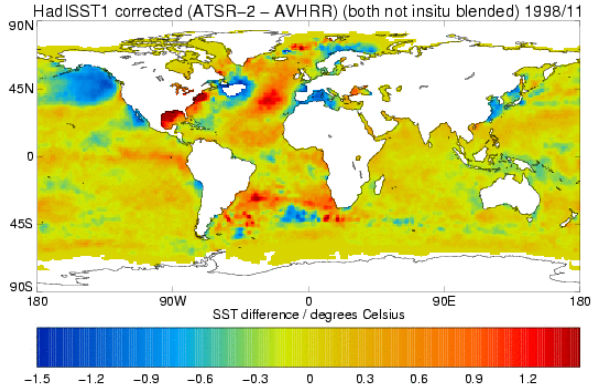

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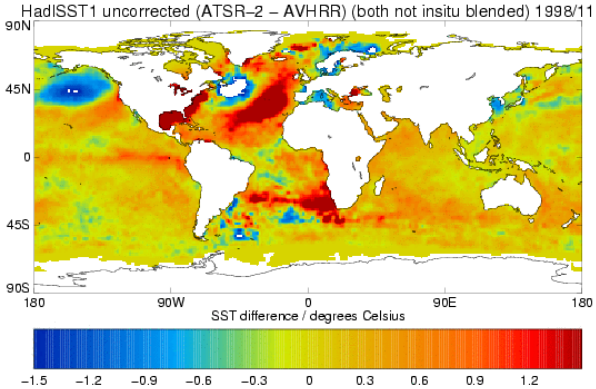
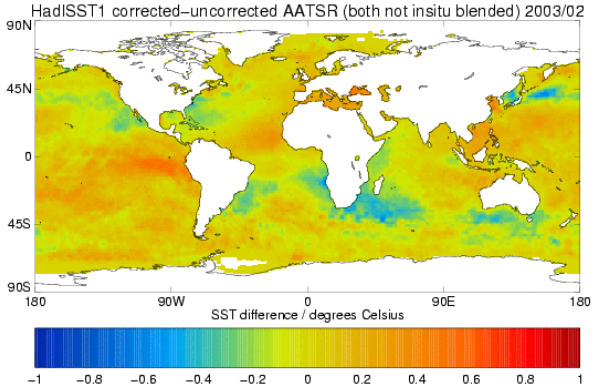


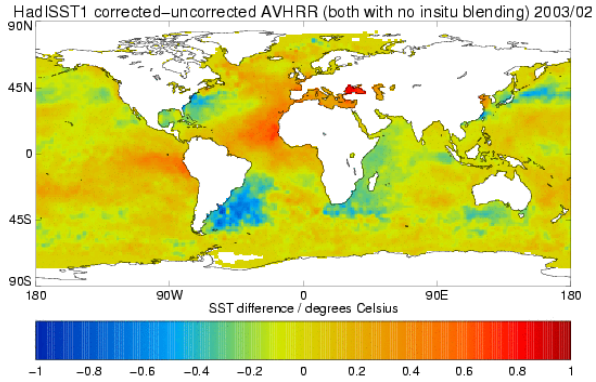
uncorrected (ATSR2 – AVHRR)

Figures 4a to 4d. Non-insitu blended results for November 1998

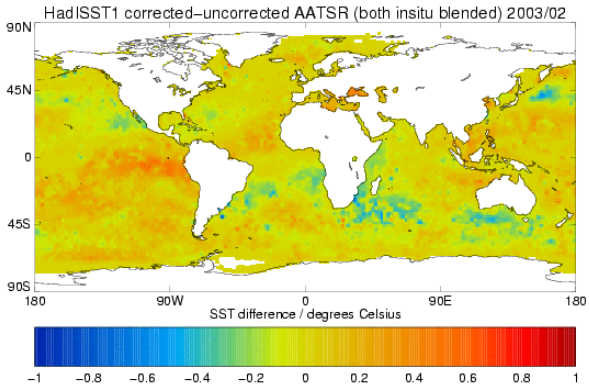
HadISST comparisons for 2003: comparing with/without bias corrections



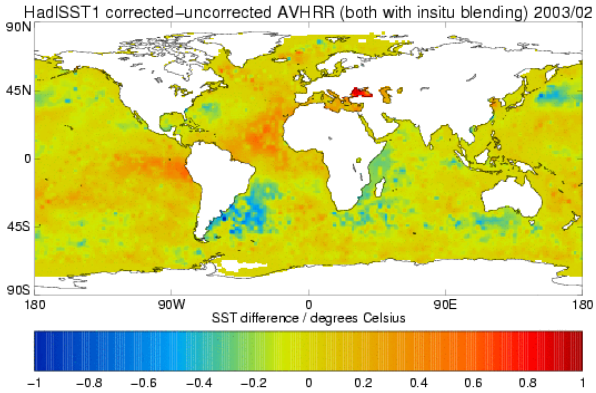
corrected – uncorrected AATSR (no insitu blending)



corrected – uncorrected AVHRR (no insitu blending)

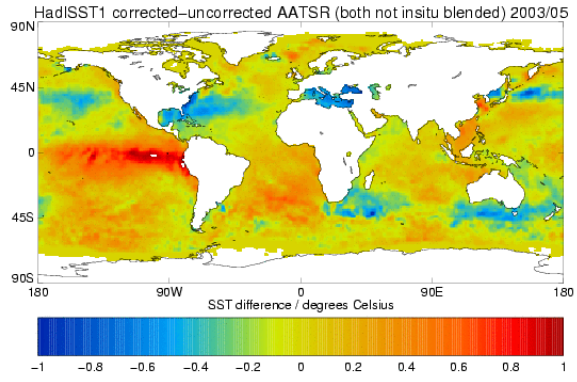


corrected – uncorrected AATSR (with insitu blending)

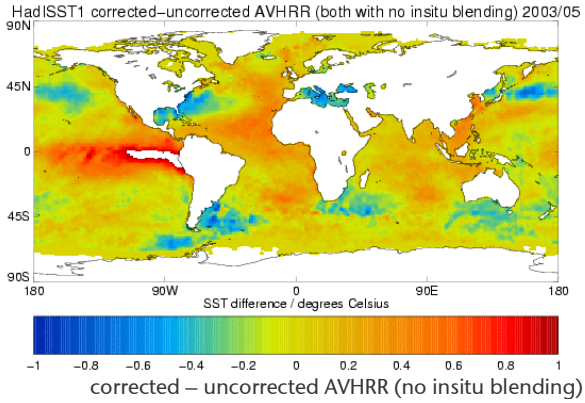


corrected – uncorrected AVHRR (with insitu blending)

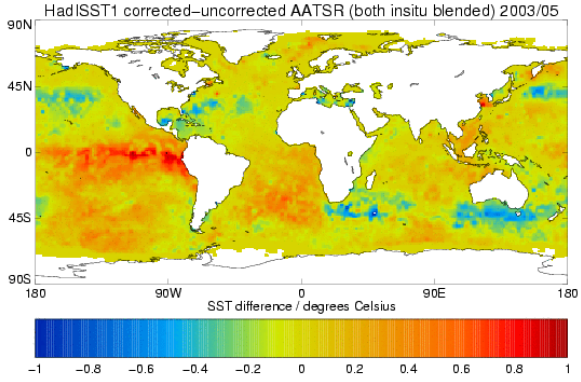
Figures 5a to 5d. Corrected – uncorrected HadISST comparisons for February 2003



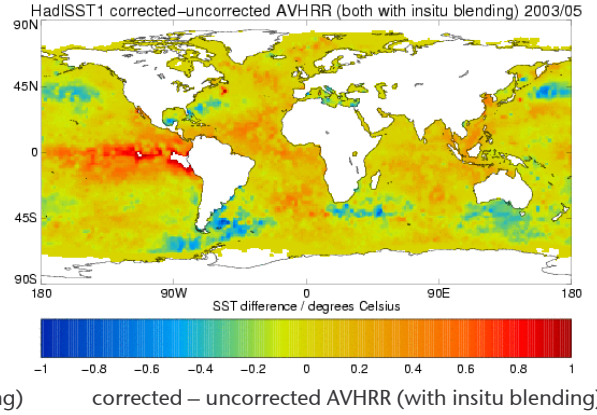
corrected – uncorrected AATSR (no insitu blending)



corrected – uncorrected AVHRR (no insitu blending)

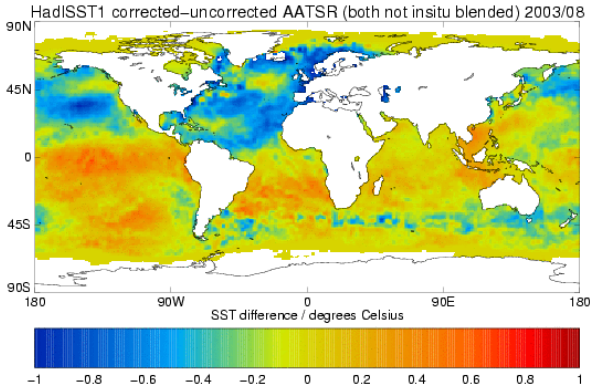


corrected – uncorrected AATSR (with insitu blending)

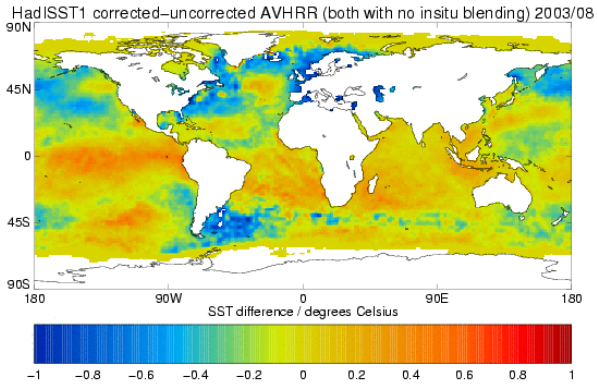


corrected – uncorrected AVHRR (with insitu blending)

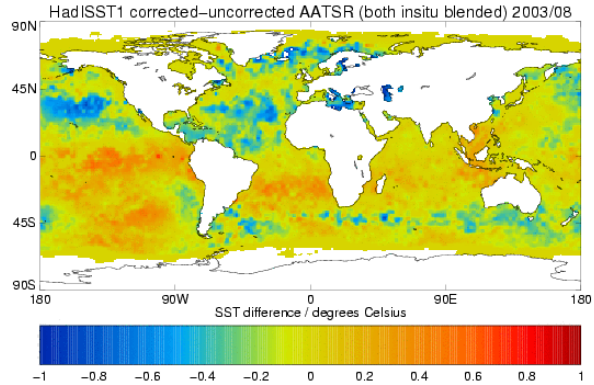
Figures 6a to 6d. Corrected – uncorrected HadISST comparisons for May 2003



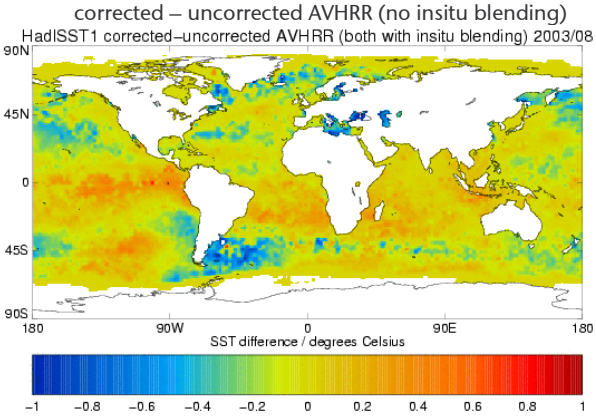
corrected – uncorrected AATSR (no insitu blending)



corrected – uncorrected AVHRR (no insitu blending)

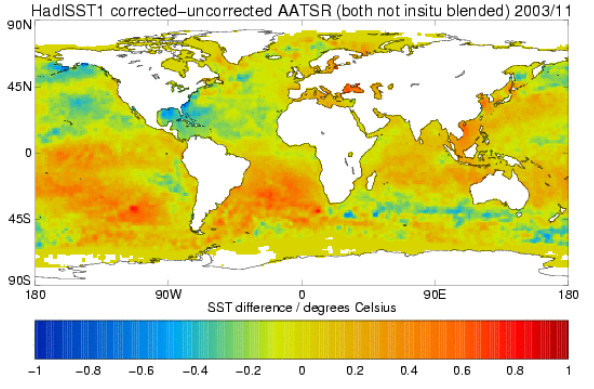


corrected – uncorrected AATSR (with insitu blending)

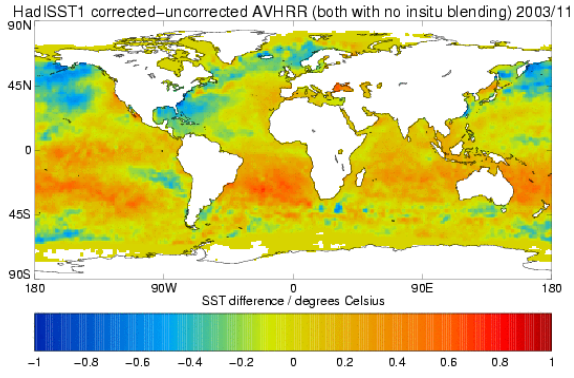


corrected – uncorrected AVHRR (with insitu blending)

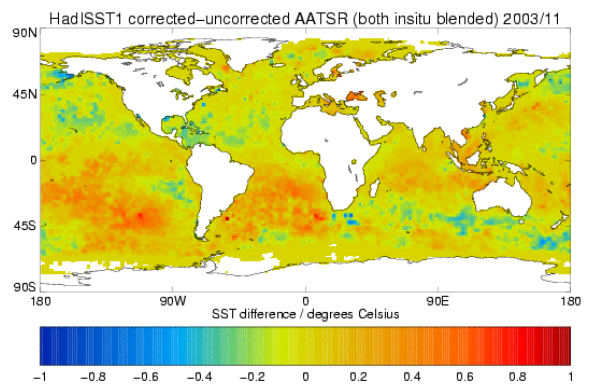
Figures 7a to 7d. Corrected – uncorrected HadISST comparisons for August 2003



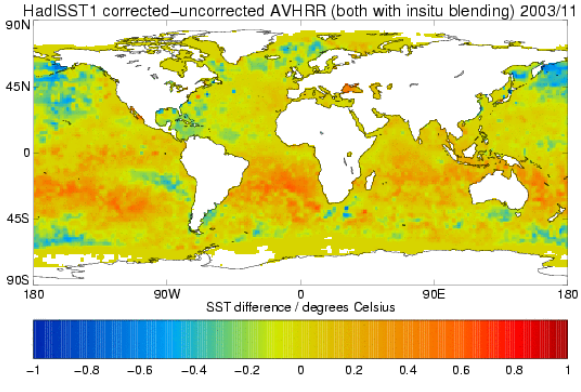
corrected – uncorrected AATSR (no insitu blending)



corrected – uncorrected AVHRR (no insitu blending)



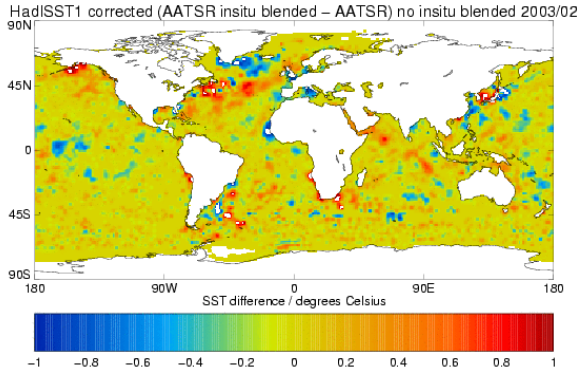
corrected – uncorrected AATSR (with insitu blending)



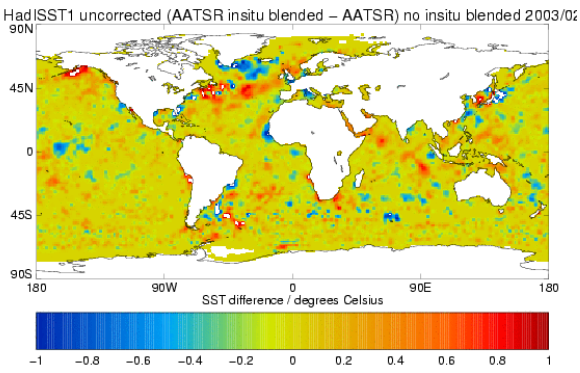
corrected – uncorrected AVHRR (with insitu blending)

Figures 8a to 8d. Corrected – uncorrected HadISST comparisons for November 2003

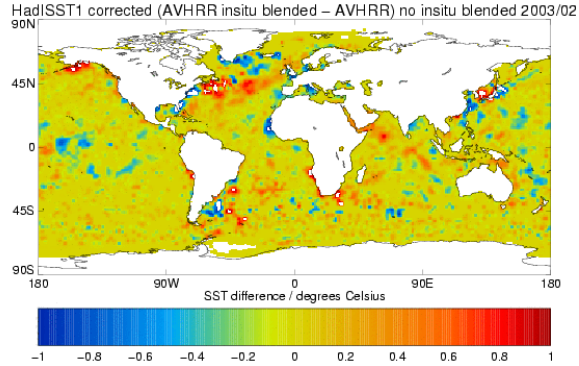
HadISST comparisons for 2003: comparing with/without insitu blending step



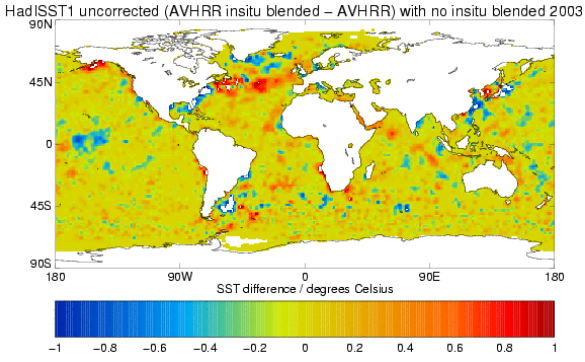
corrected AATSR (with insitu – no insitu)



uncorrected AATSR (with insitu – no insitu)

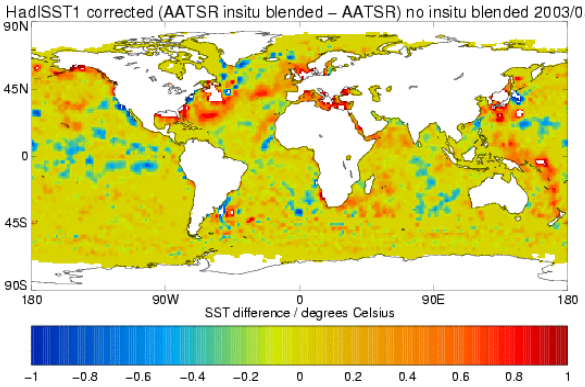


corrected AVHRR (with insitu – no insitu)

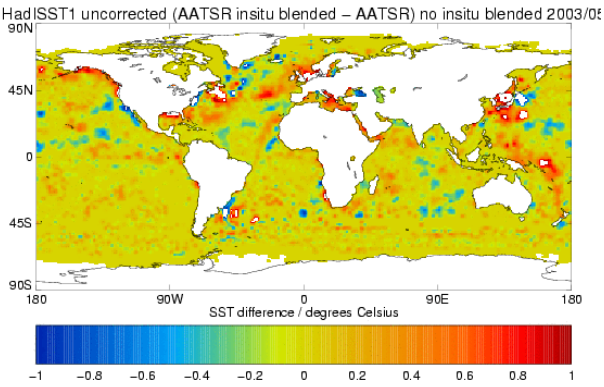


uncorrected AVHRR (with insitu – no insitu)

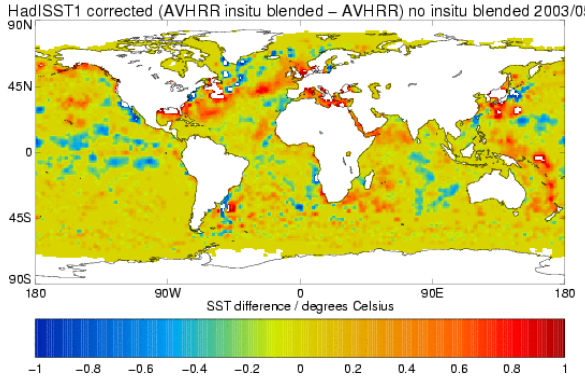
Figures 9a to 9d. With - without (insitu blending) HadISST comparisons Feb 2003



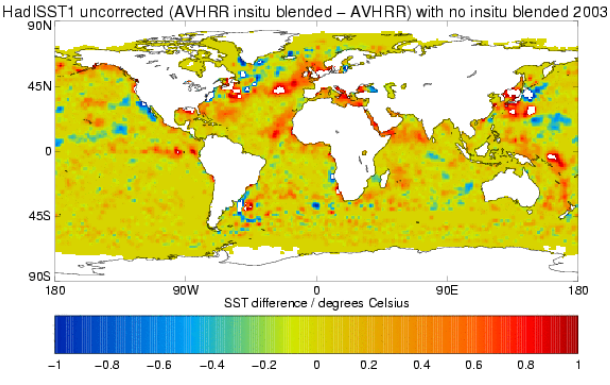
corrected AATSR (with insitu – no insitu)



uncorrected AATSR (with insitu – no insitu)

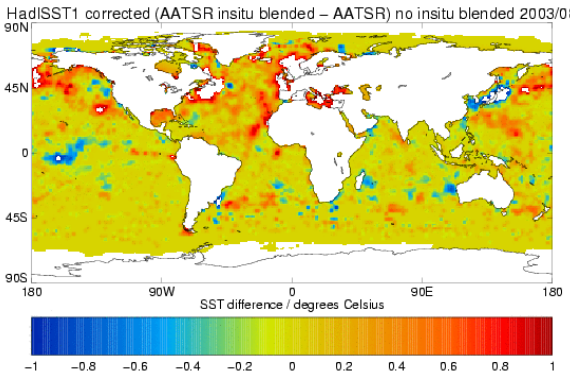


corrected AVHRR (with insitu – no insitu)

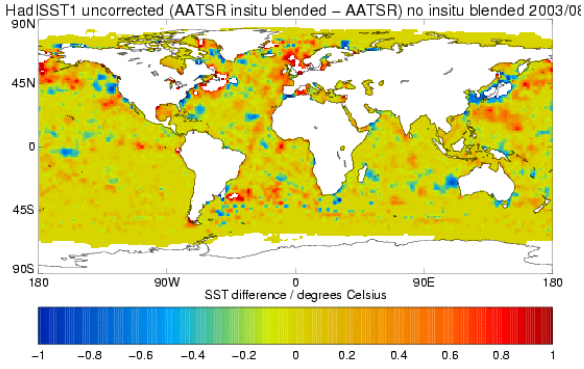


uncorrected AVHRR (with insitu – no insitu)

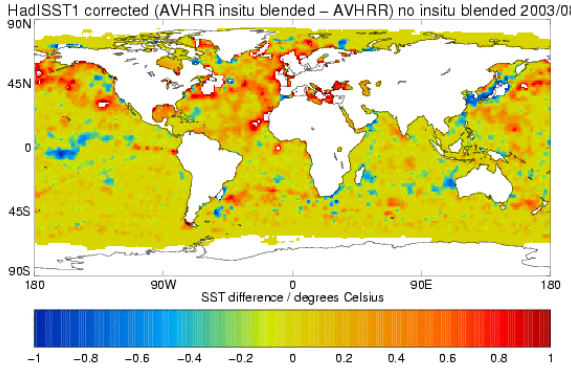
Figs 10a to 10d. With – without (insitu blending) HadISST comparisons May 2003



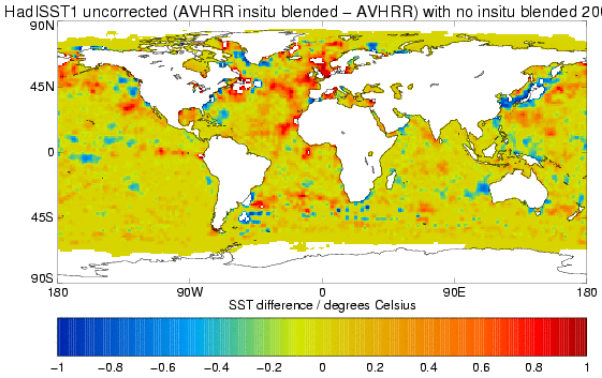
corrected AATSR (with insitu – no insitu)



uncorrected AATSR (with insitu – no insitu)

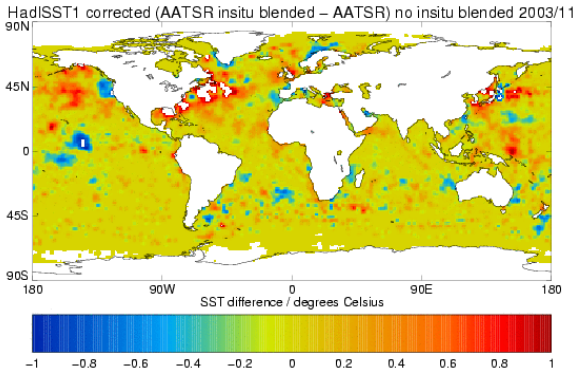


corrected AVHRR (with insitu – no insitu)

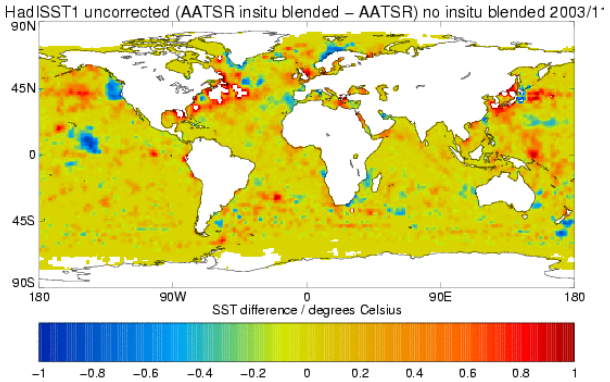


uncorrected AVHRR (with insitu – no insitu)

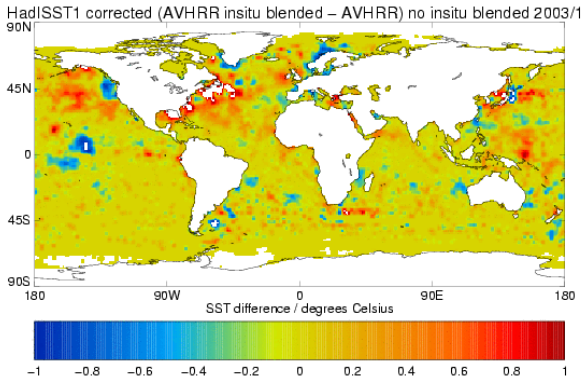
Figs 11a to 11d. With – without (insitu blending) HadISST comparisons August 2003



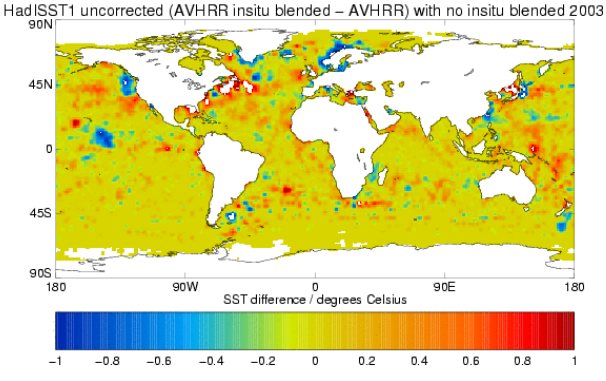
corrected AATSR (with insitu – no insitu)



uncorrected AATSR (with insitu – no insitu)



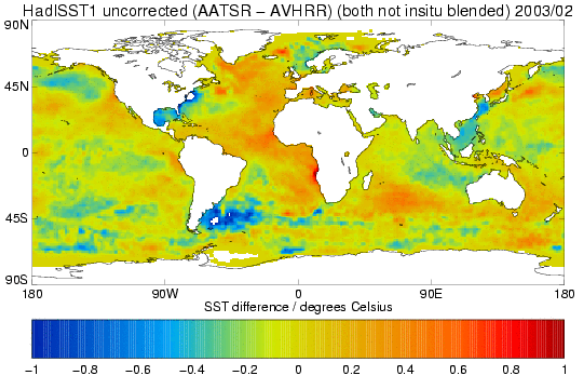
corrected AVHRR (with insitu – no insitu)



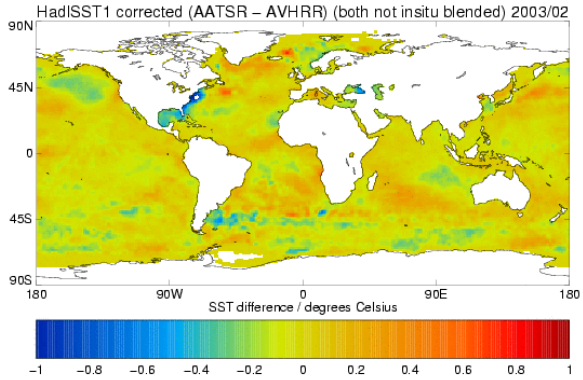
uncorrected AVHRR (with insitu – no insitu)

Figs 12a to 12d. With – without (insitu blending) HadISST comparisons Nov 2003

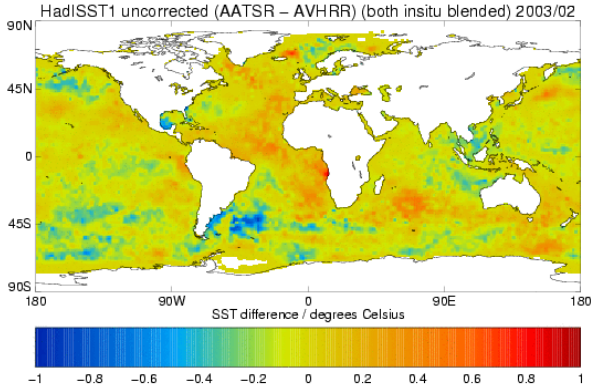
HadISST comparisons for 2003: comparing versions using AVHRR and AATSR



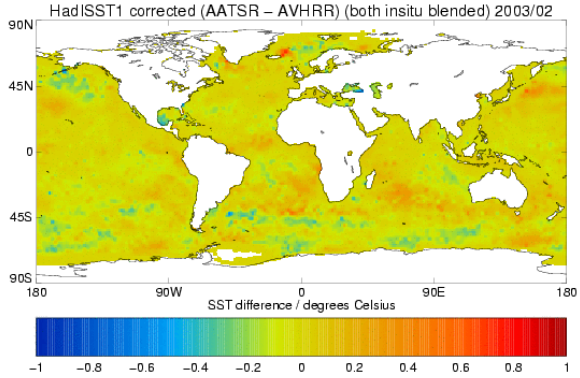
not insitu blended



not insitu blended

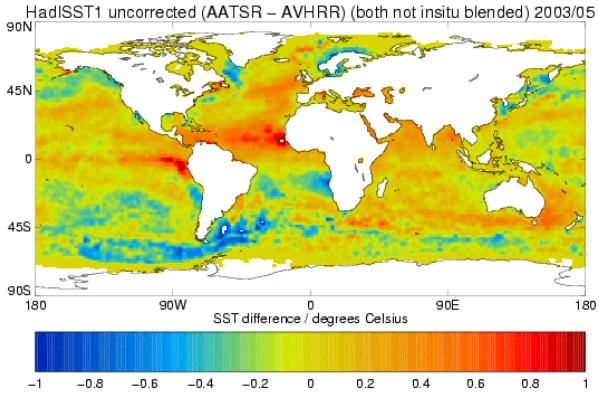


with insitu blended

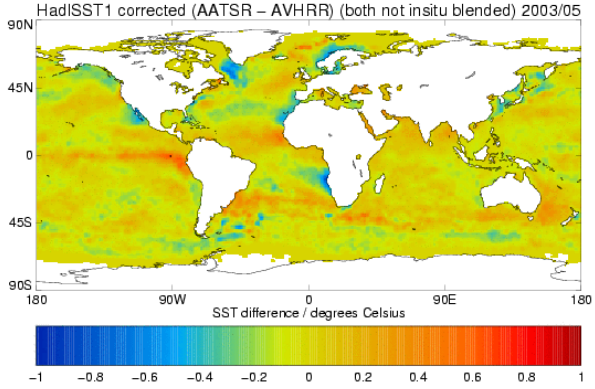


with insitu blended

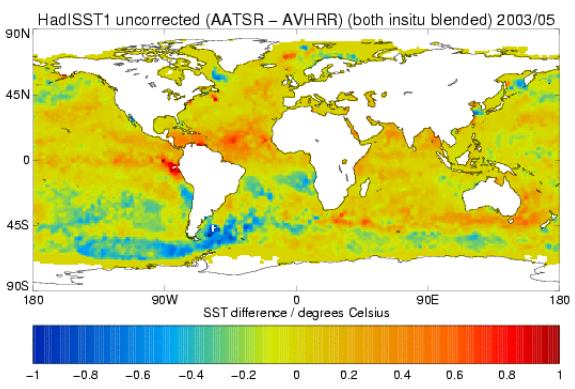
Figures 13a to 13d. HadISST comparisons (AATSR – AVHRR) February 2003



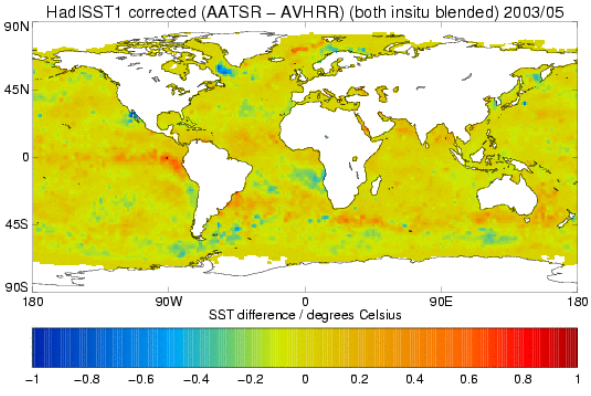
not insitu blended



not insitu blended

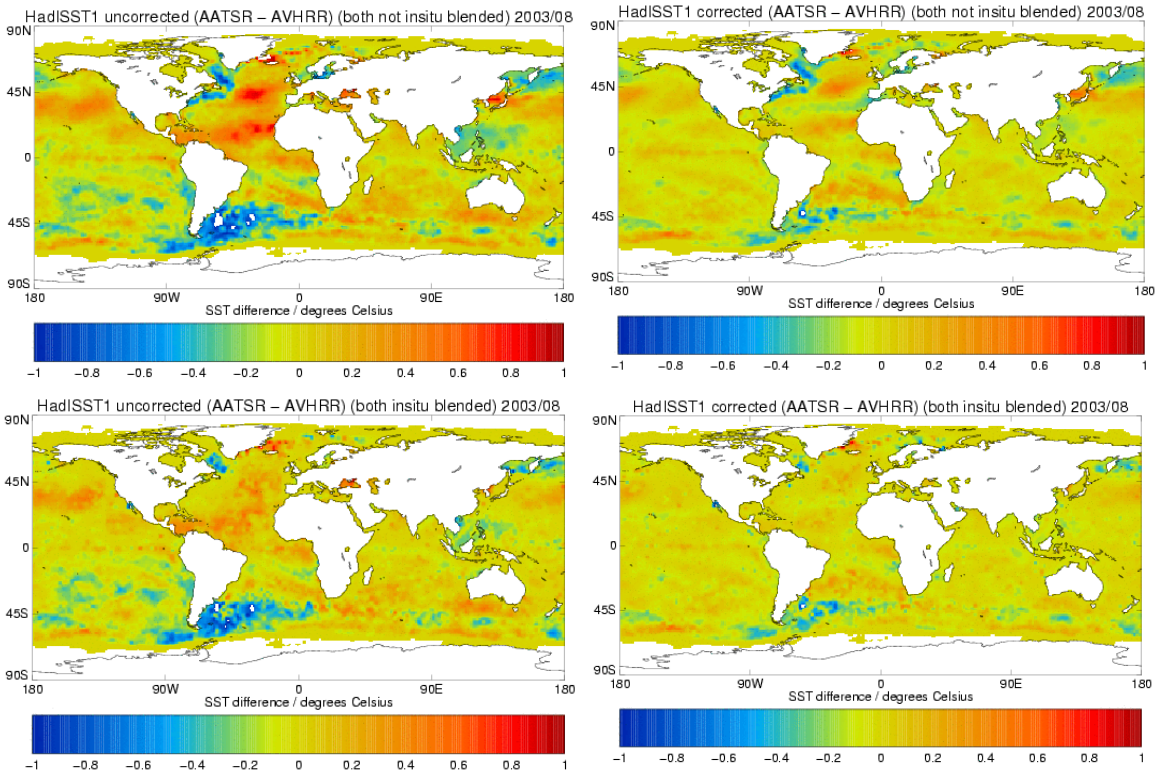


with insitu blended

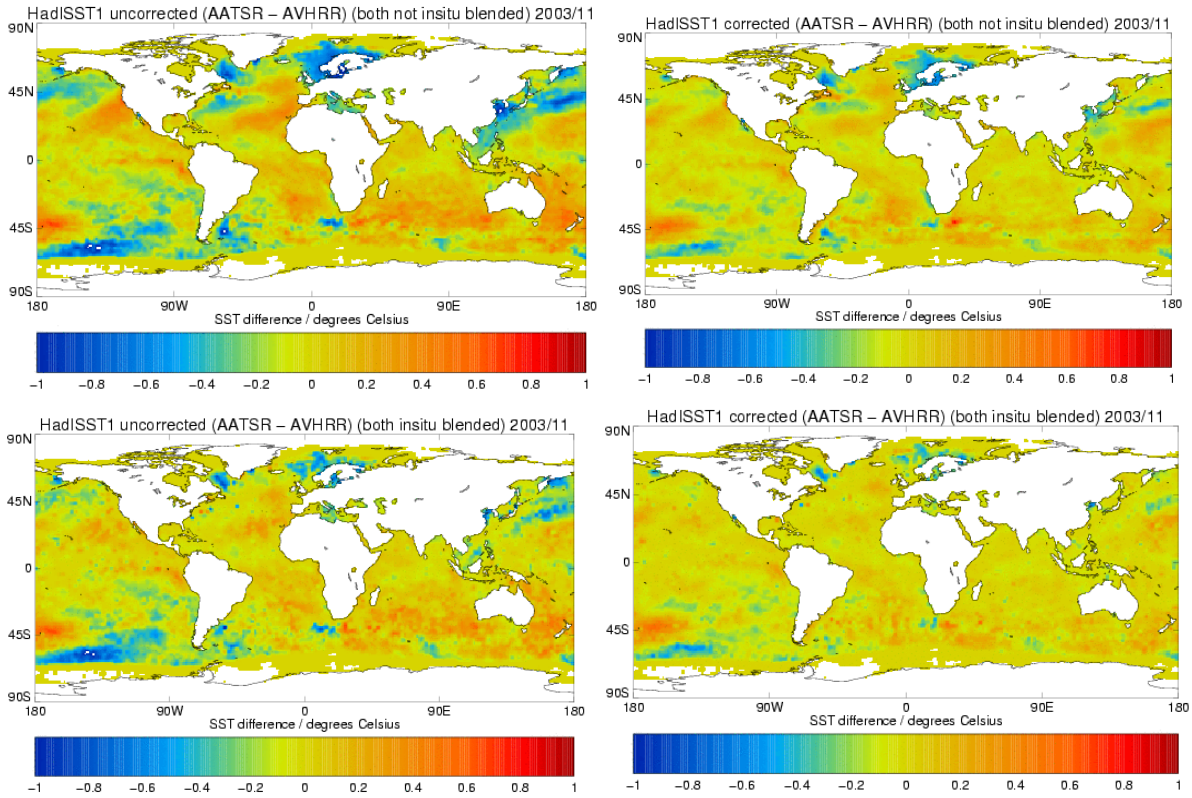


with insitu blended

Figures 14a to 14d. HadISST comparisons (AATSR – AVHRR) May 2003

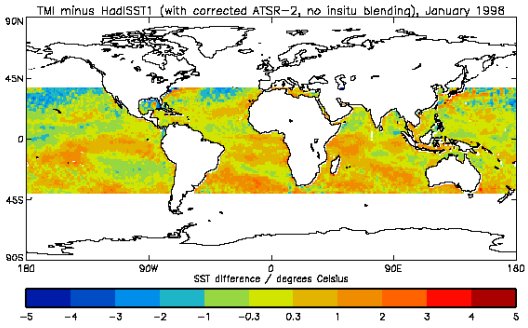


Figures 15a to 15d. HadISST comparisons (AATSR – AVHRR) August 2003

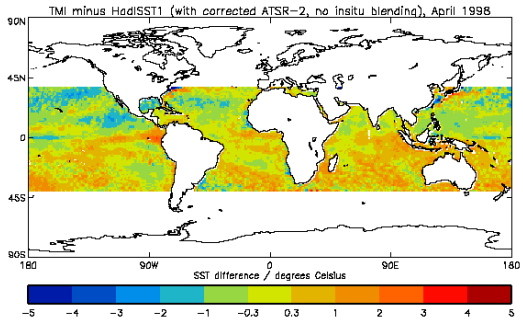


Figures 16a to 16d. HadISST comparisons (AATSR – AVHRR) November 2003

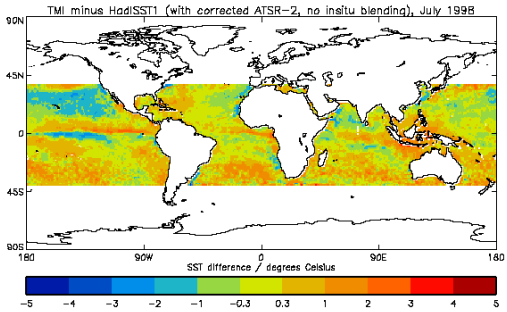
Comparison of HadISST1 (bias corrected) with validation data



January 1998

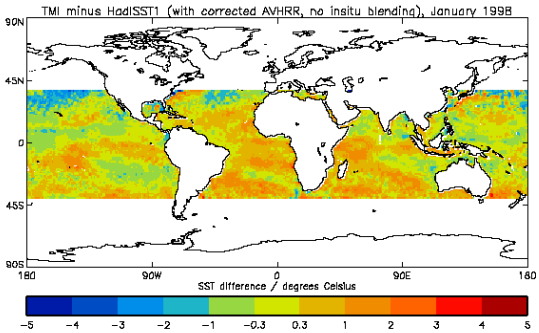


April 1998

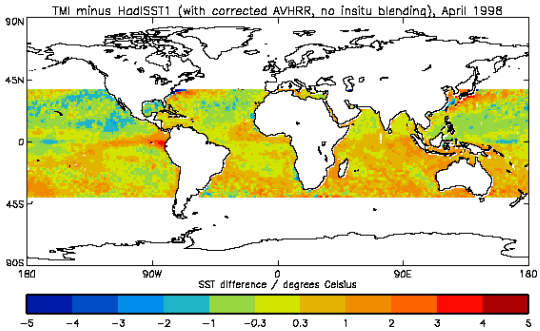


July 1998

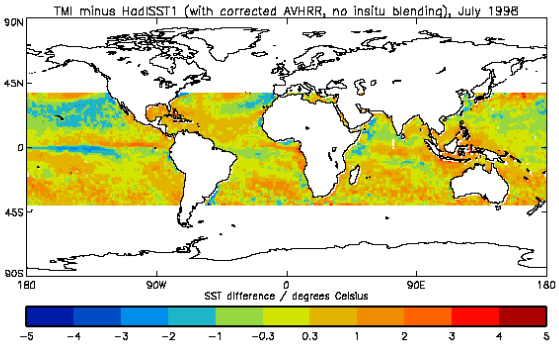
Figures 17a to 17c. TMI - HadISST1 (corrected ATSR2, no insitu blending), 1998



January 1998

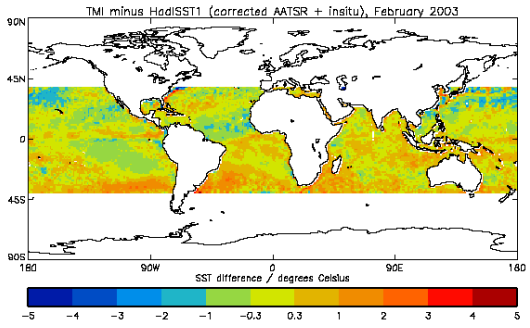


April 1998

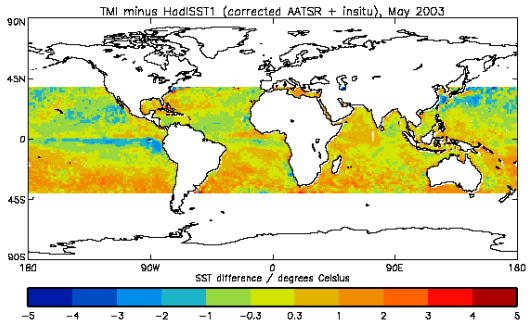


July 1998

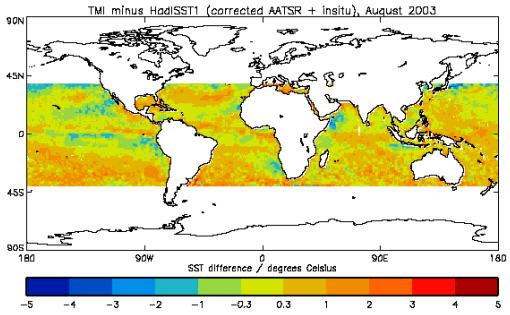
Figures 18a to 18c. TMI – HadISST1 (corrected AVHRR, no insitu blending), 1998



February 2003

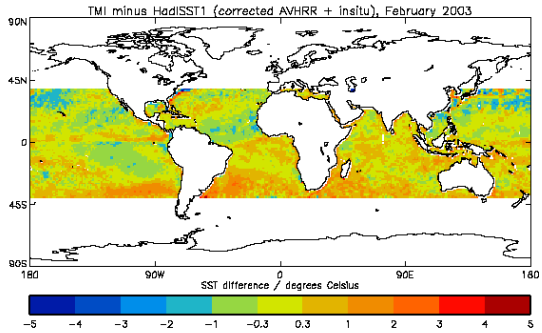


May 2003

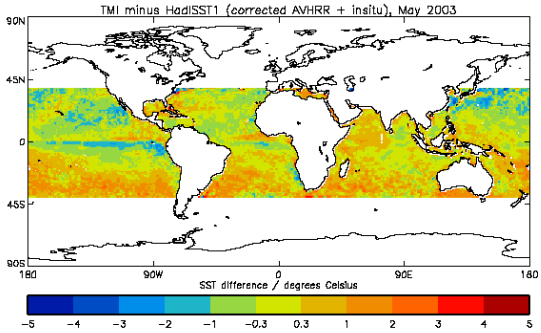


August 2003

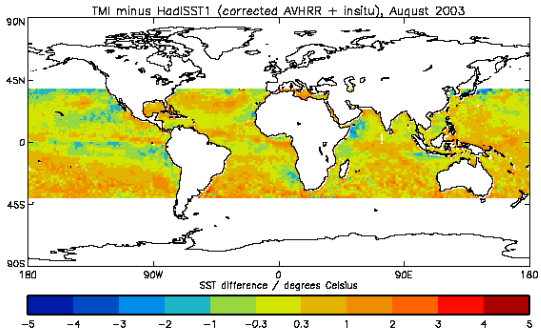
Figures 19a to 19c. TMI - HadISST1 (corrected AATSR, with insitu blending), 2003



February 2003

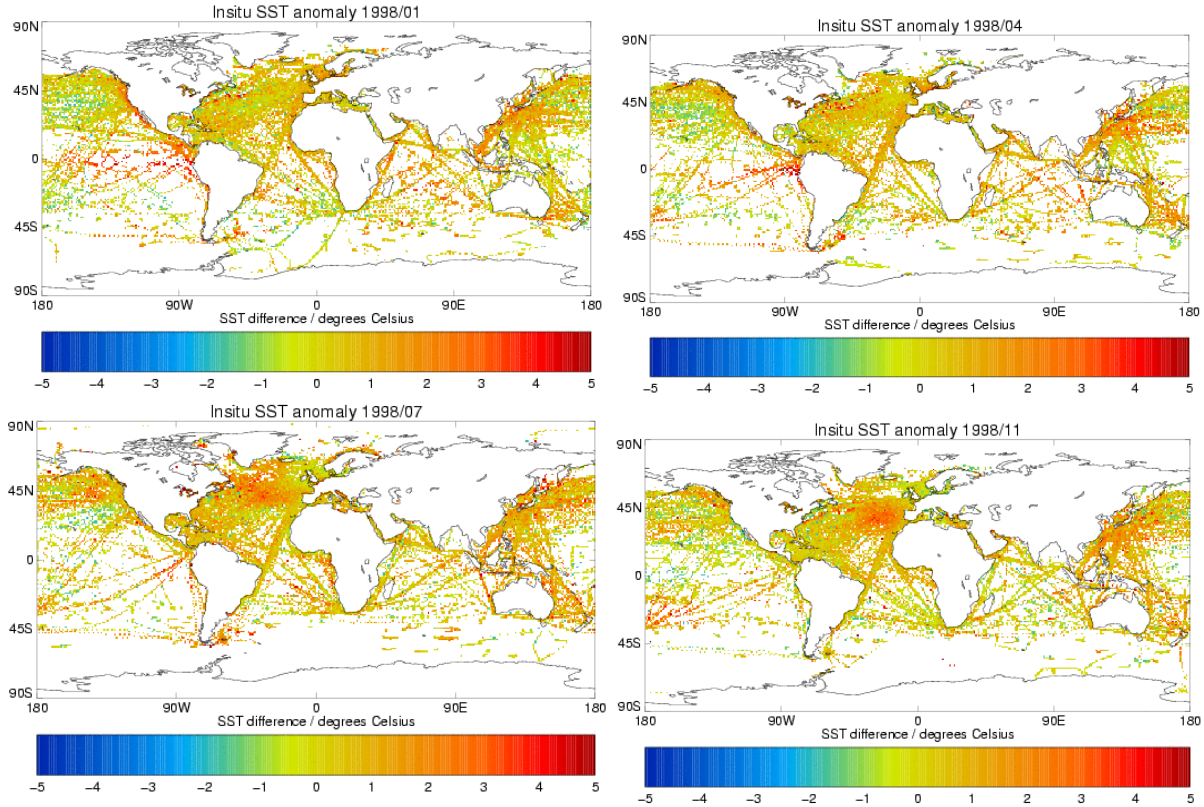


May 2003



August 2003

Figures 20a to 20c. TMI - HadISST1 (corrected AVHRR, with insitu blending), 2003



Figures 21a to 21d. In situ SST anomalies for HadISST1, January, April, July, November 1998